Technical Assistance for a Study on Forest Biomass Energy Conversion

Second Progress Delivery Report Output D2.3:

A report about the projects feasibility analysis and the prioritization methodology to select the pilot project.

2nd Progress Report

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List of Abbreviations

AFD	Agence Francaise de developpement/ French Development Agency
ALTERRE	Agrocarburants Locaux, TERritoires Ruraux et Energie/Local Biofuels, Rural Territories and Energy
AMADER	L'Agence Malienne pour le Développement de l'Energie Domestique et l'Electrification Rurale/Malian Agency for the Development of Domestic Energy and Rural Electrification
ASALs	Arid and Semi-arid Lands
BEF	Bioenergy and Food Security
BEFS RA	Évaluation rapide de la bioénergie et de la sécurité alimentaire/Bioenergy and Food Security Rapid Appraisal
BQS	Burundi Quality Stoves
BRADES	Bureau de Recherche/Action pour le Dèveloppement Solidaire
CAR	Central African Republic
CAR	Central African Republic
CCFD	Consultative Council of Women of Djiofor
CEFREPADE	Centre Francophone de Recherche Partenariale/Francophone Center for Partnership Research on Sanitation, Waste and the Environment
CFA	Central African Franc

CHP	Combined Heat and Power
CMS	Credit Mutuel du Senegal
CSR	Corporate Social Responsibility
DANIDA	Danish International Development Agency
DRC	Democratic Republic of Congo
ERND	Environment, Natural Resources and Development Network
FAFASO	Foyers Améliorés au Burkina Faso/Improved Stoves Burkina Faso
FAMALI	Foyiers Ameliores au Mali/Improved stoves in Mali
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics Division
FASEN	Foyers Améliorés au Sénégal/ Improved Stoves in Senegal
GERES	Groupe Energies Renouvelables, Environnement et Solidarités/Group for the Environment, Renewable Energy and Solidarity
GHG	Greenhouse Gas
GIE-POWERCAM	Cameroon Electricity Corporation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH/German Corporation for International Corporation GmbH
GMDR	Green Mud Dome Retort
GTZ	Gesellschaft für Technische Zusammenarbeit/German Technical Corporation Agency
GW	Gigawatts
H2CP	High Calorific Cashew Pyrolyzer
HoA-REC&N	Horn of Africa Regional Environmental Centre and Network
ICCN	Congolese Institute for Conservation of Nature
ICS	Improved Cooking Stove
IFN	Inventaire Forestier National/National Forest Inventory
IKI	Internationale Klimaschutzinitiative/ International Climate Initiative
ILF	International Lifeline Fund
KFCFCU	Kaffa Forest Coffee Farmers' Cooperative Union
kW	Kilowatts
MINEE	Ministere de L'eau et de l'energie/Ministry of Water Resources and Energy
MINEF	Ministry of Environment and Forestry
MJ	Megajoule

MW	Megawatts
NGOs	Non Governmental Organizations
Nm3	Nprmal meter cubed (unit used to measure flow of gas
ORC	Organic Rankine Cycle
PEA	Permis d'exploitation et de développement/Operating and Development Permit
PEDASB	Energie Domestique et acces aux Services de Base en Milieu Rural/Domestic Energy Project and access to basic services in rural areas
PERACOD	Programme for the promotion of renewable energy, energy efficiency and access to energy services
PNV	Viruga National Park
ProCEAO	Program for Economic Cooking Energy in West Africa
ProCGRN	Program of Management and Conservation of Natural Resources
PROGEDE	Projet de gestion durable et participative de l'énergie/Sustainable and Participatory Energy Management Project
PRONAR	Programme National d'Afforestation et de Reboisement / National Afforestation and Reforestation Programme
SEED	Entrepreneurship in Sustainable Development
SETA	Societe des Energies et Technologies d'Avant-garde
SOBAH	Emay Soba Sanayi Limited Sirketi
SODEFOR	Société de Développement Forestier/Forest Development Corporation
SOSUMO	Société Sucrière du Moso
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WFP	World Food Programme
WPUs	Wood Processing Units
ZAE	Zone d'Activité Economique/Economic Activity Zone

Glossary

Anaerobic: in the absence of free or combined oxygen

Bio-energy: electricity or gas generated from organic matter, commonly known as biomass

Biomass: above or below ground organic material from plants that is often burnt to provide energy

Briquetting: the pocess of compressing biomass residues into compressed blocks of charcoal or other combustible material

Carbonization: the conversion of organic material into carbon or carbon containing residues through use of very high temperatures

Cellulose: this is the main substance of plant cells that retains their uniform shape

Cogeneration: also known as combined heat and power, is the generation of two or more forms of energy from a single fuel source

Co-managed forests: a forest territory in which two or more actors are involved in its conservation, protection, management and oversight of its exploitation

Combustion: a process in which a substance rapidly reacts with oxygen to give off heat

Devolatization : a decomposition process where volatiles (reactive gaseous elements) are driven out of a hydrocarbon material such as coal through use of high temperatures

Digestate: the material that remains after the anaerobic digestion of biodegradable matter

Digester: a container in which substances are treated with heat, enzymes or a solvent to promote decomposition

Gasification: a thermochemical process that converts biomass directly into fuel gases of a mixture of carbon monoxide, carbon dioxide, methane, hydrogen etc.

Hydrocarbons: an organic compound consisting of only carbon and hydrogen atoms.

Industrial roundwood: this includes all wood felled for use in industries (pulpwood and veneer logs) and in the case of trade, chips, particles and wood residues

Organic liquid: any liquid that is made of volatile organic compounds, including, but not limited to carbon

Organic Rankine Cycle: the process by which a turbo generator converts combustible steam into mechanical energy and finally into electric energy through an electric generator

Pyrolysis: the use of high temperatures in the absence of oxygen to decompose organic material

Retort type reactors: a reactor that has the ability to pyrolyze wood logs of over 30 centimetres long and upto 18 centimetres wide

Rocket stoves: a specially designed stove where all air is sucked up into the unit to ensure total combustion and generating more heat energy than other conventional stoves

Syngas: an abbreviation for synthesis gas, is a gaseous mixture of carbon monoxide, carbon dioxide and hydrogen. It is released through gasification of carbonecous material. It is also known as pyrolysis gas.

Thermochemical: the use of heat to promote chemical transformations of biomass into energy and chemical products

Torrefaction: the heating of biomass in the absence of oxygen to produce biochar which has superior characteristics to coal

Transfer fluid: any gas or liquid specifically manufactured for transferring heat from one system to another

1. INTRODUCTION

93% of rural households and 58 percent of urban households in Africa depend on wood biomass. Currently, the wood biomass conversion is highly inefficient and has very low recovery rates, yet there are various technologies that could be used to convert biomass to provide more convenient forms of bioenergy. Increasing use of traditional biomass, charcoal and firewood, is a direct cause of deforestation and forest degradation in many countries of West, Central and East Africa. Food and Agriculture Organization Global Forest Resources Assessment (FRA, 2005) has estimated that the demand for energy wood in the African Forest Commission or Commission des Forêtsd'Afrique Centrale (COMIFAC) countries in 2005 was 1,317,000 m^3 of wood in the rough, or 441,572 tonnes of firewood, and it took 611,995 tonnes of wood to produce 73,734 tonnes of wood charcoal. The use of firewood and wood charcoal will continue to be essential in the coming decades, both in cities and in rural settings. This growing demand is due to the combined effect of the following three underlying causes: (i) population growth, (ii) the absence of alternative energy sources appropriate for low-income populations, and (iii) inefficient production and use of wood charcoal. To address the wood biomass inefficiency challenge the Government of the Republic of the Congo, the Democratic Republic of the Congo, the Central African Republic, the Republic of Cameroon, the Gabonese Republic, the Republic of Equatorial Guinea, the Republic of Chad, the Republic of Burundi, the Republic of Senegal, the Republic of Côte d'Ivoire, the Republic of Mali, Burkina Faso, the Togolese Republic, the Republic of Benin and the Republic of Djibouti approached the Climate Centre for Technology and Network (CTCN) for a technical assistance (TA) aimed at identifying various options for economical industrial conversion of forest waste through projects with a significant positive climatic and social impact.

1.1 Objectives and Scope of the Study

The objective of the Study is to:

- Assess the bioenergy potential from sustainable biomass sources across 15 African countries, such as wood waste from forest harvesting operations and industry;
- Improve afforestation and forest sector residues energy conversion; and
- Identify market opportunities for the private sector that will bypass the exploitation of traditional biomass sources.

The CTCN technical assistance is intended to promote projects that establish a sustainable industrial chain for forest biomass energy conversion using planted forest as raw material and forestry biomass and sawmill waste. It is anticipated to bring about the following impacts and co-benefits and contribute to country obligations to the Paris agreement through the Intended Nationally Determined Contributions (INDCs) and Sustainable Development Goals (SDGs) (Table 1).

Table 1: Project impacts, co-benefits, and contribution to INDCs and SDGs

Project Impacts	Co-benefits	Contribution to INDCs
• Sustainable industrial chain for forest biomass energy conversion using planted forest as raw material and forestry biomass and sawmill waste. • Reduction of pressure on native forests. • Increase the final bio-energy use options such as cogeneration plants that use pyrolysis gases and waste. • Significant reduction of greenhouse gas emissions thanks to more efficient charcoal production, waste conversion, increased forest cover, and decreased deforestation rates.	• Reduced greenhouse gas emissions, creation of employment through sustainable bio-energy projects. • Sustainable and efficient use of wood biomass, reduced discarded forest residues in wood processing value chains. • Contribution to the development of the COMIFAC Convergence Plan and national REDD+ processes. • Gender mainstreaming in the forestry sector.	• Reduced GHG emissions from deforestation and forest degradation • Improved forest site conditions for regeneration and planting thereby increasing carbon sequestration. • Production of electricity from sustainable sources such as forest biomass energy conversion and/or cogeneration. • Creation of a system of forest eco-industrialization in the sector

Contribution to SDGs

SDG 5 : Gender equality

- End of all forms of discrimination against all women and girls in selected countries.

SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all

- Industrial scale wood fuel will lower costs of production and improve its access; an d
- Industrial scale wood fuel and organization of artisanal producers will provide viable andsustainable wages for rural populations.

SDG 13: Take urgent action to combat climate change and its impact

- The information generated could be the base of new policies that promote the modern bio-energy sources from wood as a substitute to traditional biomass;
- Planted forests as source of raw material will strengthen the adaptation option and land restoration; and
- Industrial scale wood fuel will reduce the GHG emissions from current inefficient wood fuel production.

SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

- Industrial scale wood fuel will reduce the pressure on natural forests and thus help to forest recovery; and
- Reduced deforestation and degradation will lower GHG emissions by each of the 15 countries supported.

1.2 Technical Approach and Methodology

The TA covers six outputs, each with a set of activities:

1. Output 1: Development of implementation planning and communication documents
2. Output 2: Identification of the source of forest residues in the forest supply chain. Identification of hot spots of wastes in the supply chain in order to map the sites where the greatest amount of waste is generated
3. Output 3: Determine the requirements for and availability of technologies for converting the identified biomass resources. Bioenergy technologies to be selected must be specific for feasible solutions according to the specific context of each country
4. Output 4: Sustainability Assessment. Many factors may influence the final performance of the bioenergy end solutions proposed. The analysis must focus on risk and benefits vis a vis environmental, socio-economic, policies, business model, and funding sources factors
5. Output 5: Selection and the implementation of pilot projects (one per country)
6. Output 6: A final (1 day) workshop will be organized to present the activities of the technical assistance.

A detailed approach and methodology for each output and associated activities is provided in the proposal to CTCN. Here below we outline an abridged version of the approach and methodology. It involves three main aspects:

1. **Literature and document reviews:** This is being carried out through a review of policies, country development priority reports, past and ongoing project reports in the 15 countries focusing on the following sectors--Agriculture, Forestry, Energy, Environment, Gender and climate change processes. The aim of this exercise is to ensure that we understand countries priorities and policies regarding use of biomass energy, how the utilization of biomass in these countries affects related sectors such as agriculture, environment and socio-economic implication including gender.
2. **Consultation with main Stakeholders:** This is being carried out through intense consultations with the countries National Designated Entities (NDEs), project proponents and other key stakeholders. In this regards we have divided the 15 countries into three main areas and identified coordinators of these regions, for ease of implementation:
   - Central Africa Countries - Government of the Republic of the Congo, the Democratic Republic of the Congo, the Central African Republic, the Republic of Cameroon, the Gabonese Republic, the Republic of Equatorial Guinea and the Republic of Chad
   - West Africa Countries -the Republic of Senegal, the Republic of Côte d'Ivoire, the Republic of Mali, Burkina Faso, the Togolese Republic, the Republic of Benin and
   - East and Horn of Africa - the Republic of Burundi and the Republic of Djibouti
3. **Collection of primary data where applicable and field visits:** We have identified country contacts who are assisting in the collection of the required field data. However, due to Covid-19 pandemic very limited visits are being carried out in the initial period, with more focus on available secondary data.

This report covers Output 2.3 A report about the projects feasibility analysis and the prioritization methodology to select the pilot project. It considers the theoretical and practical success factors. It considers key success factors focusing on the technology assessment of wood energy plantations (new forests) to support the sustainability of raw material identified and to increase the conservation potential. The report has outlined factors such as forest species, land size focus in a medium-size, and others factor related, for a given country with the best feasibility conditions. Chapter 3 summarizes past bioenergy projects, challenges and lessons learnt. Chapter 4 discusses waste forest biomass availability in specific countries

2 PROJECTS TO CONSIDER: KEY SUCCESS FACTORS

2.1. Combustion (with or without compacting)

Combustion is a thermochemical transformation of carbonaceous material. When the matter reacts at high temperature with the oxygen in the air, energy is formed in the form of intense heat and light: this is the flame. Combustion can also be used as a method to treat waste, without recovering it. In this case, it is incineration without heat recovery. This case will not be studied as it is not relevant to the present work.
The materials that can be used as fuel come almost exclusively from organic matter. This includes hydrocarbons of mineral origin, as well as biomass. Ideally, any material with a high carbon content and low moisture content is a good fuel. Woody materials such as wood residues are of course suitable for combustion, but also other non-wood residues from trees, such as the shells and pits of their fruit. It can also be a question of liquid or gaseous fuels: there are also forms of residual biomass in this state. A summary is given in Table x.
The main reason for choosing a waste as fuel is the cost savings gained by substituting a more expensive conventional fuel. However, this is not always the case, whether for logistical, technical or deliberate reasons. Also, the substitution of wood with a solid waste fuel acts directly to reduce the pressure on the natural tree resource, which can result in a reduction in deforestation.
There are three forms of combustion that convert biomass into usable fuel (Baker, 2018). These are:
Direct combustion - this is the burning of biomass in the presence of oxygen. The steam that is generated in the process is harnessed for kinetic energy, such as turning turbines.

Pyrolysis – this is the burning of biomass in the absence of oxygen at a temperature range of 300 to 900°C. The products from this process are biochar, gas and oil. During the pyrolysis process, some volatile compounds composed of carbon, carbon monoxide and hydrogen are released while the carbonaceous residue is left behind.

Torrefaction – in this process, biomass is heated at a lower temperature than that used in pyrolysis (200 – 400°C) to produce a coal-like material known as biocoal. The biocoal product has better fuel characteristics than biomass. Torrefaction is preferred because of it grindability (easy to crush) and can be a potential substitute for coal. During the torrefaction process, the biomass is first chopped and then fed into a reactor where all water and volatile gases are separated in a process called devolatization. After the devolatization process, a dark solid remains called torrefied biomass or char.

Table 2: Fuel forms by origin and state of aggregation

	Mineral fuels	Residual biomass
Solid	Charcoal Peat	Wood residues Non-timber plant residues Carbonized residues
Liquid	Oil (and liquid refined derivatives)	Vegetable oil Pyrolysis liquid
Gas	Natural Gas Butane, propane, etc.	Biogas Gasification gas (syngas)

2.1.1 Direct combustion for domestic purposes

A daily gesture dating back to the origins of humanity, fire has been used to provide heat for households since time immemorial. Although there are currently other heating solutions that do not depend on wood energy (butane gas, electric kitchens), the former remains the preferred option for a very large part of the population. The most commonly used forms are bundles of wood and charcoal.

The technologies used to burn this solid biomass are very diverse and depend as much on the end use of the heat (cooking, water heating, indoor air heating) as on the means of acquisition of the user. The aim of this work is not to make a catalogue of all these technologies; however, it is relevant to define the main types of solid biomass fireplaces, especially those that are most commonly used in the countries under study.

Figure 1:Traditional three-stone stove (foreground) and improved artisanal stove (background, right) in Burkina Faso

Indeed, the "three-stone" or traditional fireplace is the basic option for households, especially the humblest. Thermal efficiency is quite poor, between 5 and 15%. Energy loss is high due to the exposure of the fireplace to the outside. This is because combustion takes place in an open space, so hot gases easily escape into the ambient air instead of heating the target utensil. So-called "improved" fireplaces enclose the combustion space to better direct the hot gases to the target. The efficiencies increase by up to 20 to 35%. This translates into fuel savings compared to the traditional fireplace, which is over 50%. There is a wide variety of improved fireplace models available on the market. The most efficient are those built in clay, as this material retains heat very well. However, clay fireplaces are more fragile, sometimes require maintenance by the user, and are often less mobile (especially for larger sizes). Metal fireplaces are, in comparison, lighter and often simpler in construction. However, they retain heat less well, and are therefore often less efficient. In order to combine the advantages of both types of fireplaces, models can be built with a mixture of these two materials. However, as the sophistication of the fireplace increases, so does the cost. Finally, the price of improved cookstoves is often the main obstacle to acquisition for a public that is not used to investing in cooking equipment, and which poorly quantifies the loss of income through fuel savings.

Other benefits of improved cookstoves are the reduction of smoke (some include a chimney directing smoke to the outside), resulting in tangible improvements in family health, reduction of fire (burns), reduction in the time needed for heating and if it is also the case for the acquisition of fuel.

2.1.2 Direct combustion for industrial purposes

2.1.2.1 In standard burning equipment

Currently, combustion is required not only at the household level but also for productive activities in industries. Many industrial activities require a fuel source to operate. To give examples, the food and beverage industry, cement (clinker) plants and the metallurgical industry need heat for their production processes.
The technologies used to burn waste are very diverse. Depending on the end use of the heat, different equipment will be used. The heating of water or another fluid is done in a boiler, the heating of air can be done directly in a furnace. In all cases, the fuel is burnt in a furnace, which is a chamber specially designed to house the fuel and at the same time ensure maximum heat transfer from the flame to the material to be heated.
The configuration of this equipment, and in particular its hearth, depends on the nature of the fuel. In some cases, the equipment is suitable for the combustion of several types of fuel; in others, a slight modification can be made to adapt the equipment to the new fuel. For example, when wood is replaced by a smaller fuel, such as cashew nuts, a modification to the firebox grate must be made. On the other hand, sometimes it is necessary to have specific equipment in order to be able to recover a certain type of waste; this is the case of powdery waste such as sawdust or shea cake, which must be fed continuously, or compacted in order to be fed in batches.
The scale of combustion equipment is very wide. The smallest furnaces and boilers consume only a few kg of fuel per hour, the largest ones up to several tons per hour.
Combustion efficiency is measured as the heat transferred to the heat transfer medium (water, air, etc.) in relation to the total energy released during complete combustion. The efficiencies can vary widely depending on the technology, ranging from 20% for locally manufactured boilers without insulation to over 80%.
Many industries still use wood as fuel. As a substitute for wood, some industries are switching to burning their own waste. This is the case of sawmills to dry their sawn timber and veneer, or food processing units.
Some manufacturers use liquid fuels (heavy fuel oil, residual oils) or gaseous fuels.

1.1.3. Combustion for power generation

1.1.3.1. Steam turbine

To produce electricity from a solid fuel such as woody biomass, the most extensive system is the steam turbine system. Devices can range from a minimum of 1MW up to several hundred MW; although models from 500kW upwards can be found on the market, the cost per unit of power becomes much higher than larger scale models. As for installations in the upper end of the power range, biomass plants often do not exceed 20 MW, due to the difficulties of having large deposits of biomass waste at a competitive cost.

The installation consists of a boiler, where the biomass is burned completely to generate high-pressure steam. The steam then expands in the turbine, which drives an electric generator. The low-pressure steam at the boiler outlet condenses in a condenser, and then returns to the boiler again.

The advantages of the steam turbine are its reliability, reduced need for maintenance/repair and the relatively high availability of suppliers under the market. Overall it is the most mastered technology for the valorization of dry biomass.

The disadvantages are, as stated, high capital costs and limited electrical efficiency, particularly for smaller systems. In these cases, controlled operation of the system is essential to reap the benefits, keeping the availability factor high (operation of >5000 h/year), maximising the added value given to the heat, and ensuring high availability of raw material with the required quality.

1.1.3.2. ORC (Organic Rankine Cycle)

ORCs follow the same principle as steam turbine cycles (evaporation of a heat transfer fluid for expansion in a turbine, which converts thermal energy into mechanical and then electrical energy). The difference is in the heat transfer fluid, which instead of being water is an organic liquid. This fluid behaves differently to water in terms of the conditions for its evaporation and energy absorption; this allows, by choosing the appropriate substance, to work at lower temperature and pressure, and therefore to operate in milder conditions.
It is possible with this type of technology to recover heat from low temperature sources, such as waste heat, geothermal and solar thermal.
When used in combination with combustion systems, this can reduce investment costs on the boiler and also less material fatigue due to lower working temperatures. The organic fluid is also non-erosive and non-corrosive. Also, the equipment responds better to partial load than the steam analog.
ORC systems are typically available for small and medium power, up to a few MWé. On this power fringe, OCRs are slightly more efficient than steam cycles (around 17-21% gross electrical efficiency). On the other hand, the technology has the disadvantage that the organic fluid needs to be highly controlled to avoid losses due to leaks, or its ageing, which requires a dedicated and closed system, unlike water.

1.1.3.3. Steam engines

An alternative to turbines but still using steam are steam engines. This is one of the first technologies to be developed: the first trains were powered by a steam engine. Indeed, the expanding steam actuates the pistons of the engine. This linear movement becomes rotary with a conventional crank rod system. In order to produce electrical energy, an alternator is added which transforms the movement into electricity. With the arrival of the new internal combustion engines, this technology fell into oblivion because it was much less efficient than its heirs (5-10% compared to 20% for diesel engines), which were larger and more expensive.
Nevertheless, there are still a few manufacturers, the power range being in the small capacities (a few kWé to about 1MWé).
The advantages of the technology are its simplicity of operation, robustness and adaptability to a wide range of fuels. However, the choice of suppliers is becoming scarce, as this technology is becoming less and less widespread.

1.1.3.4. Combined Heat and power (CHP)

The electrical efficiencies of the systems presented above are moderate (around 15% for small steam turbine systems). In fact, electricity generation alone produces very large amounts of waste heat (in the form of low-pressure steam, heat losses in the turbine and at the condenser). This waste heat requires at least 50% of the primary energy supplied by the fuel; but it can be as high as 90% in the least efficient systems.

The overall efficiency of the system can be improved if this waste heat is used; at the moment we are talking about cogeneration (combined generation of electricity and heat). Cogeneration schemes are especially interesting when the heat covers the needs of a large heat demand. This can be an industrial process or a district heating network. Approximately 80% of the input energy provided by the fuel can be recovered as heat, so the overall efficiency can be around 90% (including electrical and thermal efficiency).

2.2. Co-firing

2.2.1 Industrial co-firing

2.2.1.1 Carbonization (with or without compacting)

Coal is the solid product of the pyrolysis of a raw material. It is in fact the remaining carbonaceous "residue" from the high-temperature decomposition of the material. Pyrolysis is indeed a degradation process very similar to combustion, the main difference being the supply of oxygen (comburent). The lack of ventilation limits the rise in temperature of the carbon + oxygen reaction, and avoids the degradation of the organic matter up to the gas stage. On the other hand, the lightest ("volatile") matter is released. The remainder is a "fixed" carbon-rich material.

In Africa, charcoal is unquestionably one of the most widely used wood-based fuels, especially in urban areas. It is appreciated because it is not dirty and does not generate smoke (in fact, the volatile material having already been released, the flame slowly consumes the fixed carbon). The most widespread techniques are the traditional millstones, consisting of piling up the raw material (fresh or dry wood), covering it with earth and starting a fire in the lower part. Part of the raw material is then consumed in order to heat up the whole to carbonization temperatures. Material yields rarely exceed 15%. Sometimes, if the process is not closely followed, it is even possible that leaks in the heap allow unwanted air to enter, which eventually consumes the material completely. The carbonization process to take several weeks (an average of 10 days). The carbonization smoke released are loaded with volatile organic elements and are often sucked up by people in the surrounding area, which is harmful to their health.

2.2.1.1. Improved carbonization

Improved carbonization techniques include sealing the process (limiting air ingress); promoting the homogeneous distribution of heat so as not to have over-consumed materials or unburned materials; recycling as much as possible the hot gases (which are, in themselves, combustible) while reducing the consumption of the raw material; and better directing the exhaust fumes upwards. Thus, we speak of "improved millstones", "retort" type reactors (figure X), "metal furnaces", etc., which can be used to reduce the consumption of the raw material. Yields vary according to the technology used, ranging from 25% to 35%. Carbonization times are often shorter than with traditional grinding wheels; the arduousness of the work is also significantly reduced, as are atmospheric emissions.

Figure 2: Improved GMDR Masonry Grinding Wheel

Larger (industrial) models operate in an automated manner, and even the most advanced ones include a pyrolysis smoke exhaust to a recovery device, coupled to an electrical generator. The latter systems require considerable technical expertise and the very high availability of raw material (approximately 50,000 tons/year of wood).

Figure 3: General view of an industrial carbonization plant equipped with a device for generating electricity by recovering pyrolysis gases in France

Source: A-S., 2017

The barriers to the adoption of improved carbonization techniques and technologies are most often economic. Indeed, most of the technologies require an initial investment (metal or masonry furnaces, or at least an earthworks), whereas the section of the population dedicated to carbonization activities is the one that lacks the most means. In second place, and linked to the lack of means, are the operators' capacities to master or accept change to improved techniques; and finally the lack of organization and deregulation of the sector, which, despite being at the heart of the production of a common consumer good, is most of the time the great oblivion of social, economic and environmental public policies.

2.2.1.2. Carbonization of biomass waste

Swift presentation of the technologies adapted to biomass wastes (they are smaller in size, so even if the charring process follows the same principles described before, the devices could not be all the same).
Based on findings/documentation, give the capacity range (smallest, biggest setting). And which kind of residues are charred. Once the waste is charred, it needs to be grinded and compacted into briquettes. This is a prominent difference with regards to wood charcoal, so explain the impacts of this on the whole process.
Finally, state about advantages and downsides of charring biowaste instead of wood.
You can join photos.

2.3 Gasification

A thermochemical process very close to combustion and pyrolysis, gasification consists of generating a fuel gas from biomass (mainly solid). This gas is also called "syngas" or "lean gas" because of the high content of inert gases (carbon dioxide, nitrogen). It can be used for heat production or as a fuel in gas or diesel engines to generate electricity. The gasification gas has a calorific value in the range of 4 to 6 J/Nm3.
Gasification is the recommended solution for materials that are difficult to recover by combustion (small seeds and shells, heaped material and/or material too moist to be burned efficiently).

2.3.1. Gasification in cookstoves

For these materials that are difficult to convert into domestic fuel, for example because of their granulometry, or because of the release of too much smoke, some improved fireplaces induce a gasification of the fuel, by injecting a measured quantity of air, sufficient to start the gas reduction process. It is the gas released that is subsequently burnt, and the user obtains coal at the end of the use.

The rocket stoves are an example of this. They are often quite complex fireplaces, often even needing a power supply (look for pictures), and are therefore more expensive to purchase than conventional improved fireplaces; the main reason for their limited success.

2.3.2. Gasification in industrial settings

The most common type of gasifier is the fixed bed type. If there are gasifiers used solely for thermal purposes, the system can also be coupled with a gas scrubbing system and a motor for electricity generation. The most common models operate at scales from 10 to 500 kW. When the syngas is used for electricity generation, after being washed it is injected into an internal combustion engine.

The advantages of gasification systems are their high electrical efficiency compared to steam cycle systems, load variability (as they can operate well below rated capacity), the wide range of feedstock eligible and the possibility of being used with existing generators. Constraints include the relatively complicated operation and maintenance, the sensitivity of the system to fuel quality, and potential environmental and technical difficulties generated by these (tar-laden) gases. In addition, the African experience shows that it is necessary to ensure a skilled workforce to operate them, and that the availability of spare parts or technical assistance can become an insurmountable challenge. Although these systems are very suitable for 'difficult to convert' materials and small scales, there have been very few successful examples of their implementation in community-managed sites.

2.4. Liquid Bio-fuel

In addition to energy crops (oilseeds for biodiesel, sugar plants for bioethanol), liquid biomass waste can be used to produce fuels that can be used either as a motor or a burner. This is the case for cashew nut shell liquid or pyrolysis liquids recovered after carbonization.
Crude vegetable oil can be used as a substitute for diesel or fuel oil, without essential modifications to the combustion equipment, provided that the fuel viscosity, acidity and other quality parameters are respected. In order to achieve the required levels, the fuel can be fed in a mixture with conventional fuel, or lightly treated (preheating, chemical reaction). This pre-treatment of the biofuel may be simple in some cases, but it can be a step in itself and add complexity to the final installation. The degree of refining of oil or liquid material will be determining on the maintenance needs of the system (vegetable and pyrolysis oils often cause filter blockages or corrosion of certain components).
The advantage of using crude vegetable oils is that it is possible to use these fuels in systems as accessible as small generators, in combination with diesel (typically a 20-30% oil/70-80% diesel blend).

2.5. Biogas

Biogas is a flammable gas produced by the bacterial decomposition of organic matter under anaerobic conditions. It is composed mainly of methane and carbon dioxide, along with other gases such as water vapour and hydrogen sulphide. The calorific value is close to 20MJ/Nm3, much higher than the gasification gas.

The biogas raw matter can have a wide variety of origins. Animal manure is widely used, and generally considered an easy source for obtaining biogas. Other types of (drier) organic waste such as kitchen waste, slaughterhouse waste or food processing waste are also suitable for this recovery. Forest waste itself has high lignin levels and is therefore not easily digestible. The fruits (pulp remains) of trees could however be a good input for methanization.

The digestate coming out of the process is a fluid that still contains most of the mineral nutrients available in the raw material, and can therefore be used as a fertilizer in agriculture.

The system consists mainly of a digester where the conversion reactions take place; gas treatment equipment for pressure regulation and reduction to the required limits of the harmful gases for the downstream stage (mainly water and sulphur hydroxide); and finally an upgrading device. The biogas can be used for cooking, boiler heating, lighting, or as fuel in gas or diesel engines. On a large scale, therefore, biogas systems can be used to produce electricity.

The main advantages of biogas are its limited complexity and dangerousness, the possibility of recovering wet biomass (waste otherwise complicated to manage), the versatility of the product (biogas) and the added value of the by-product (digestate as fertilizer). As for the disadvantages, biogas yields are highly variable depending on the technology chosen and therefore on the investment. The end use of the biogas also determines the size of the investment, which may be private. In some cases, the main concern is rather the logistics of feedstock supply.

2.6. Chemical and Biochemical Conversion

In chemical conversion, chemical agents are introduced to breakdown biomass into other fuels such as biofuel. The chemical agents breakdown the cellulose to combustible fuel. On the other hand, biochemical processes use fermentation bacteria under anaerobic conditions to break down the cellulose to simple sugars such as glucose and xylose. These sugars are further fermented in special conditions to form ethanol (Soudham, 2015). Chemical and biochemical conversion processes are, however more costly due to the materials and reagents required, which also make their fuel products more costly than those from combustion processes (Chen, 2012).

3 SUMMARY OF PAST PILOT PROJECTS ON BIOENERGY AND LESSONS LEARNT

3.1. East Africa Countries

3.1.1 Burundi

Most households in Burundi rely on firewood as cooking fuel. Many rural households of Burundi have been beneficiaries of improved cooking stove (ICS) programs. Two examples are the stoves granted by Burundi Quality Stoves (BQS) and the International Lifeline Fund (ILF) (ILF, 2016). ILFs cookstove's project was running from 2016 to 2019 (WFP, 2017). The Burundi Quality Stoves program, (the Project Design Document stated 26th June 2012 as the start date, progress status unknown aimed to replace the use of manual stoves and firewood for 99 schools identified in the project (UNFCCC, 2014). The ICSs were manufactured by a Turkish company, SOBAH. The supply of firewood would be replaced with briquettes, which would be manufactured and sourced from Bujumbura (West), Gitega (East) and Rutana (south east). Bujumbura and Gitega would make briquettes using coffee husks and Pinus residues, while Rutana would use bagasse from SOSUMO sugar factory. The project was expected to save 36,889 tonnes of briquettes annually.

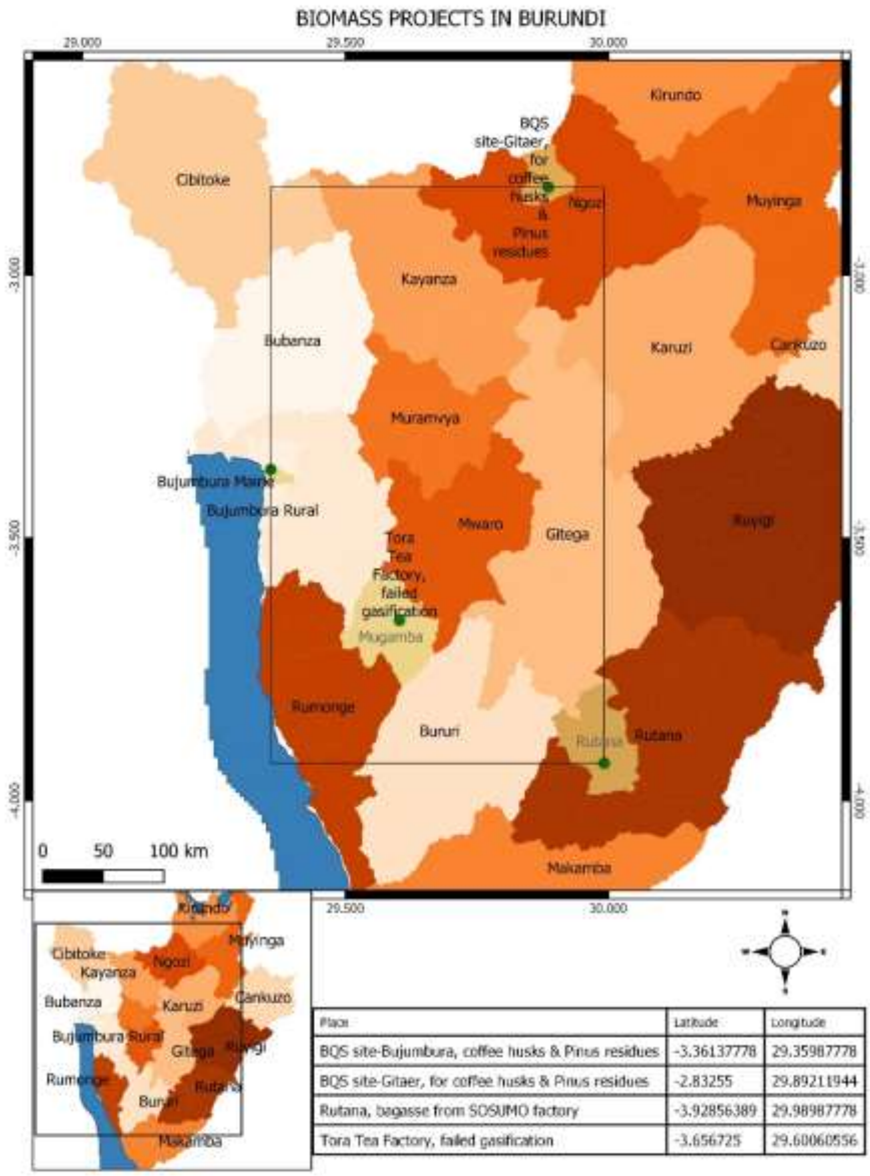

Figure 4: Biomass projects in Burundi

A gasifier was installed at Tora tea factory in Burundi in 1983. The Belgium designed gasifier was to use peat as raw material but could also alternatively work with woodfuel. However, the gasifier was no longer operational by 1985.

3.1.1.1 Challenges

Mechanical deficiencies – the gasifier at Tora tea factory was known to have frequent breakdowns.

Lack of goodwill from management – the gasifier at Tora tea factory was fed with a raw material which it was not designed for, in this case wood fuel. This could have contributed to the frequent breakdowns. The management did not also consider proactive measures to keep the machinery running, such as making appropriate repairs and sufficient technical training.

Financial constraints – the lack of capital, coupled with poverty makes the learning institutions of Burundi to rely on woodfuel and traditional cooking stoves. The economic impoverishment of the households means that the schools cannot raise capital to replace inefficient stoves and raw firewood with clean cooking fuels.

3.1.1.2 Lessons Learnt

The success of Improved cooking stove (ICS) programs in Burundi has been due to convenience and simplicity of their products. For example, the stoves provided by ILF have conical designs that accommodate various cooking styles and pots used by the locals.

Government support is crucial to boost investor confidence. The Burundian government has been encouraging foreign investment into the country's biomass potential by improving the business environment. There has been noticeable increase in foreign companies investing on biomass related industries such as SOSUMO sugar factory.

Oversight of biomass related projects is to be conducted by a reputable authority. In the case of Burundi Quality Stoves projects, the UNFCCC is the main funder and executioner of the project, working through the local manufacturer, Burundi Quality Stoves (no other status report could be found apart from the project design document, therefore progress could not be ascertained).

It is crucial to identify source of raw materials for a biomass project. The source should also be able to sustain the project in the long term. In the case of the UNFCCC funded project, the raw materials would be sourced from three strategic sites.

3.1.2 Djibouti

Djibouti is mainly a semi-arid country with very few biomass resources compared to other East African states. There is, however, the use of *Prosopis juliflora* by Holl Holl and Ali Addeh camps as fuel wood. The camps sheltered approximately 23,000 refugees in 2017 (Gianvenuti, 2018)(the refugee figures were sourced from the report authors). The two camps, when combined, require a supply of 7,359 tonnes of fuelwood every year. A project by United Nations High Commissioner for Refugees (UNHCR) in 2017 presented Prosopis as a better alternative to fuel wood. For sustainable production, the feasibility project proposed conversion of Prosopis to briquettes and charcoal. Briquetting was found to reduce the volume of wood used in transport and cooking.

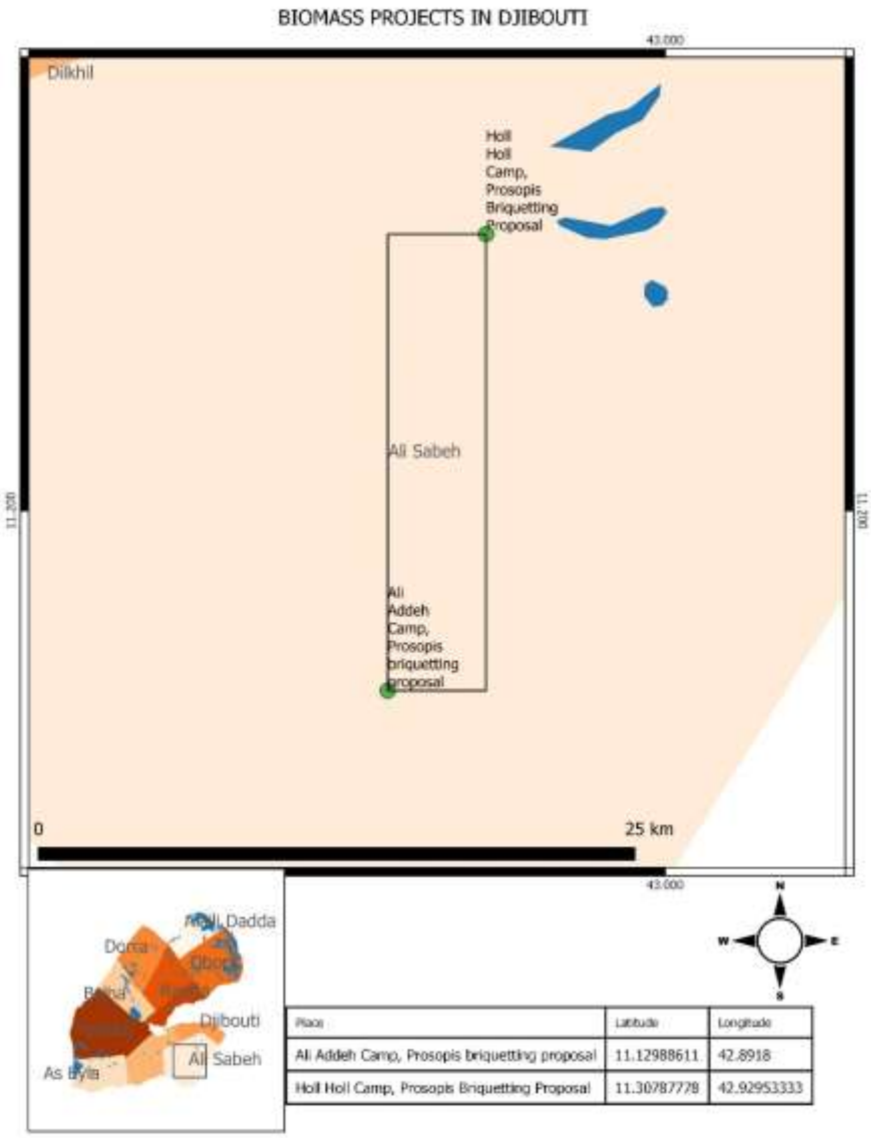

Figure 5: Biomass projects in Djibouti

3.1.2.1 Challenges

Biophysical – the aridity of Djibouti cancels out any utilization of biomass resources at large scale as it would increase the aridity of the country.

3.1.2.2 Lessons Learnt

Alternative sources to woodfuel in Arid and Semi-arid areas (ASALS) should be sought as much as possible. A pragmatic approach is to be taken in the utilization of invasive plants to stop the plant from being an invasive species.

If alternatives are few, innovative methods to be used in harnessing the Prosopis or other woody biomass such that lower woody volumes are used to generate equal amounts of energy.

3.1.3 Ethiopia

Prosopis juliflora is a native South American plant that has invaded over one million hectares of land in Ethiopia. The destructive Prosopis plant is used as an alternative cooking fuel to firewood in the Bur Amino refugee camp. The Bur Amino cooperative social group is responsible for processing the Prosopis to briquettes and their sale. The briquetting machine was provided by IKEA. The machine strips the bark, chops the wood and grinds the products to form briquettes. The Prosopis is sourced from a site 20 kilometres away, called Doll Ado near the Somalia border. This briquetting process is also replicated by cooperatives in four other refugee camps namely Bokolmanyo, Melkadida, Kobe, and Hilaweyn.

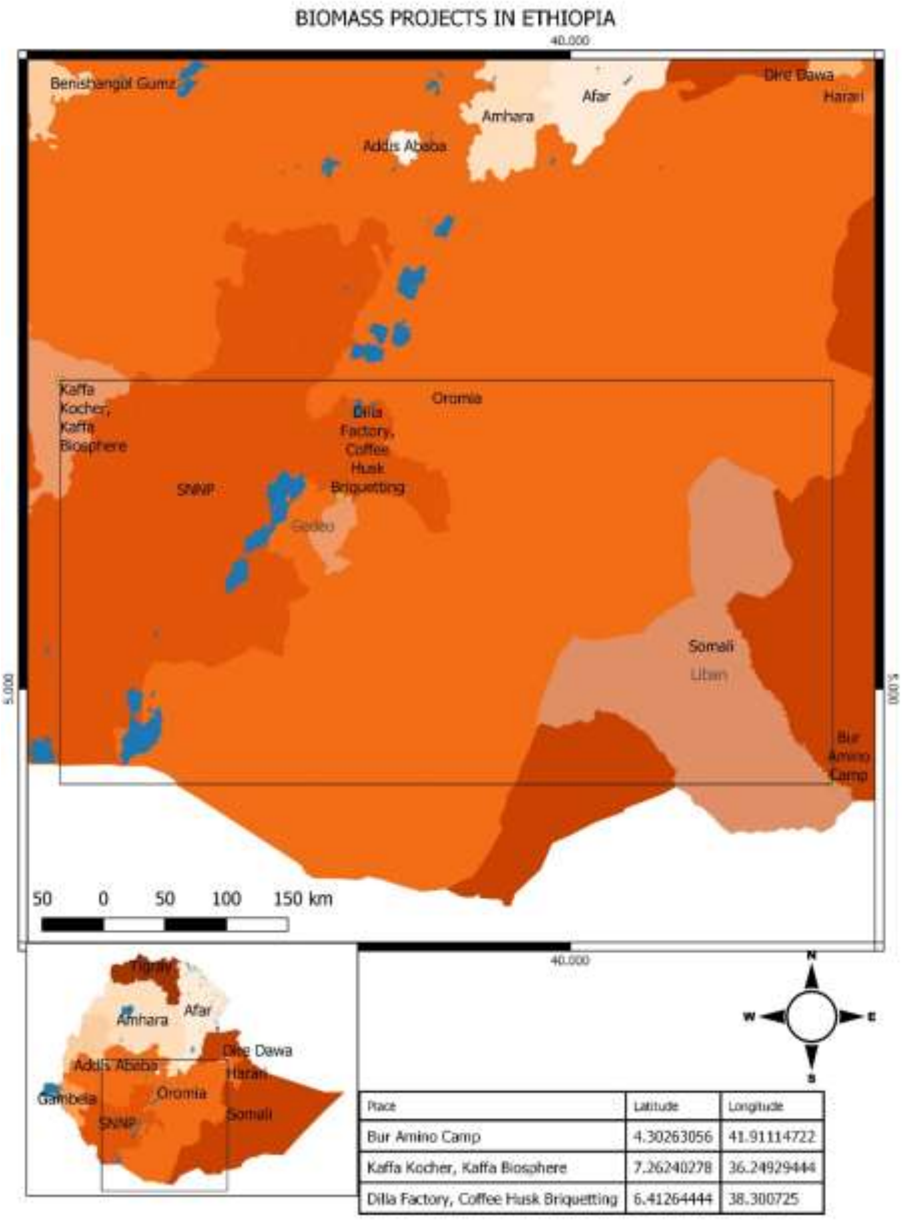

Figure 6: Biomass projects in Ethiopia

The Kaffa Kocher project in Ethiopia intended to recycle waste coffee husks that would be used as raw material for the Injera cooking stove. The pilot project was located at the Kaffa mountains, south west of Ethiopia. The coffee husks would be gasified to biochar within the ICSs, which the locals could scoop and exchange for more coffee husks from the local dehulling station, Kaffa Forest Coffee Farmers' Cooperative Union (KFCFCU). The project required a supply of 500 tonnes of coffee husks, but only 300 – 350 tonnes were available. However, the project faced temporary setbacks from adoption attributed to the stove design. The Kaffa kocher project also aimed to reduce deforestation in the Kaffa mountains, which is a UNESCO biosphere reserve since 2010 and an area of naturally growing coffee shrubs.

The agro-based economy of Ethiopia led to the establishment of briquetting plants in the 1980s to convert the agricultural waste into useful products. The Dilla briquetting factory was set up in 1985 but was not operational until 2012. This was after the Horn of Africa Regional Environment Centre and Network (HoA-REC&N), from Addis Ababa university decided to revive the plant. The plant uses coffee husks to produce briquettes, with a production capacity of 1800 – 5400 tonnes per year. The plant also channels some of its finances as a social responsibility to the Gedeo community association to improve on community infrastructure. The briquettes are distributed to Dilla's surroundings and fuel scarce areas like Arsi-Negelle in the Central Rift Valley region.

3.1.3.1 Challenges

Unsustainability – most biomass projects in the refugee camps will not sustain themselves once donor funding is withdrawn. The travel restrictions and hostility towards refugees make the Prosopis harvesting more of a household necessity than as a viable business idea. Locals also see sale of Prosopis briquettes by non-locals (refugees) as posing competition to their local businesses. This further fuels animosity towards the refugees.

Lack of political goodwill – many briquetting factories were proposed for construction in the 1980s. However, most never commenced operations even though their funding was fully catered for by international agencies. For example, DANIDA funded the construction in the 1980s but HoA-REC&N provided the technical capacity upon its launch in 2012.

System design failures – in the case of Kaffa Kocher project, the tests of ICSs using coffee husks delivered inconsistent results. At some point, coffee husks were considered an unfavourable material. The bulkiness of the ICS prevented early adoption by the host community who preferred lighter stoves with more flexibility in cooking.

Lack of awareness – as in the case of the Kaffa Kocher project, most of the locals and coffee milling factories did not have knowledge on the use of coffee husks as cooking fuel and for cogeneration in industries.

3.1.3.2 Lessons Learnt

Sufficient testing should be done on a product before marketing. Extensive tests should be taken on the biomass material to be used, such as sourcing the material from different sources and under different conditions. This will ensure the product designed is sturdy against various qualities of the biomass to be used, which are dependent on source, storage conditions and weather. For example, quality of coffee berries is not homogenous everywhere.

The use of agricultural residues should be encouraged where possible, especially at locales close to sensitive ecosystems. This will require increasing knowledge awareness.

Public private partnerships to run large scale biomass projects. The competitive nature of the private sector can be harnessed to provide the technical capacity and business skills to government-initiated projects.

3.2. Central Africa

3.2.1. Cameroon

3.2.1.1. Biomass power plant project in Africa

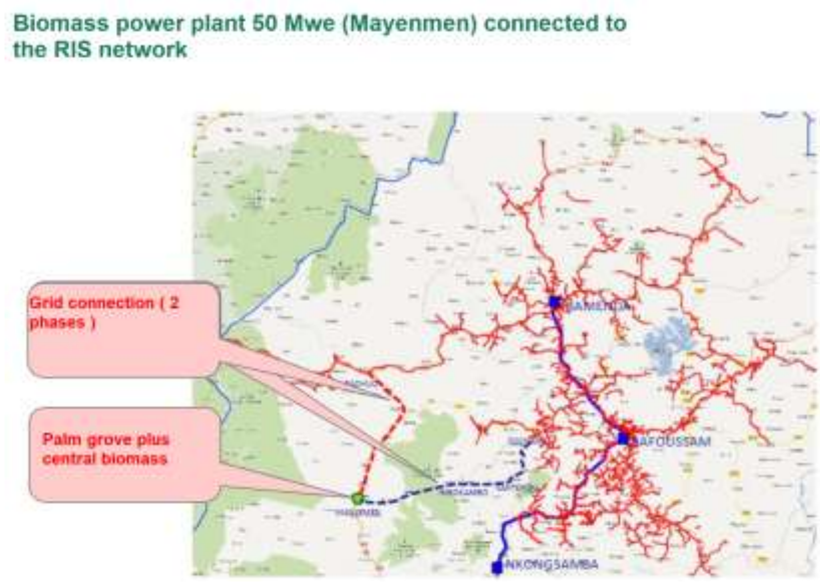

Figure 7: Biomass project connection to main grid in Cameroon

The Central Biomass Project in Cameroon is a project that is in agreement with the MINEE for a private-public partnership type financing with an investment of USD 141,600,000.This project should allow a recovery and a connection of 50Mwe with ENEO. The promoter of the GIE-POWERCAM project with its partner, GENERAL ELECTRIC, is the promoter of the GIE-POWERCAM project with its partner, GENERAL ELECTRIC, to produce caseific biomass ANKUR (India) and electricity generators (biogas). The project proposes the installation of a 22 MW gas generating plant in Manyemen in the South-West region of Cameroon. This plant has a production capacity of 160 GWh/year from wood chips and other agroforestry waste. This biomass comes from wood chips and palm grove waste[1].

3.2.2. SETA Cameroon

Seta Cameroon was contracted by 26 January 2018 involves the construction of two 5MW grid-connected biomass power plants in rural Cameroon and is the most recent addition to REPP’s portfolio of supported projects in sub-Saharan Africa. The power plants are planned for the cities of Ebolowa and Edea in the coastal and southern regions of Cameroon. Once built, they will supply baseload power and additional grid stabilization in a rural area known for its weak grid system, displacing light fuel oil and gas generation[2].

[1] *http://www.acp-france.org/wp-content/uploads/2016/01/6.Power-Cameroun.pdf*
[2] *http://repp.energy/wp-content/uploads/2018/11/Case-study-Seta-Cameroon.pdf*

3.2.2.1. Challenges

- Issues relating to the availability of finances for large projects, environment and regional conflicts are almost common among developing countries like Cameroon. In addition, the developing countries face institutional constraints, policy issues, exchange rate fluctuations, security
- Availability limited by the biomass generating speed.
- High cost of initial investment for compatible power supply.
- Insufficient yield for the size of the localities retained
- Greenhouse gas emissions

3.2.3. Gabon

3.2.3.1. Agricultural and Forest Waste Recovery for Sustainable Energy Project

The project for the recovery of agricultural and forestry waste in Gabon for sustainable energy started in 2013 and should be completed in 2020. It is an innovative pilot project initiated by UNDP Gabon to transform agricultural and forestry waste, wood chips, sugar cane waste and other agricultural residues to produce clean coal briquettes for cooking facilities and electricity generation[3].

3.2.3.1.1. Challenges

The main challenges related to this project are :

1. Lack of manpower due to the rural exodus of young people attracted by job opportunities on forestry farms.
2. Difficulties in transporting waste from the plantations to the power generation unit
3. The sanitary nuisance of waste storage sites.

3.2.4. Democratic Republic of Congo (DRC)

3.2.4.1. Production of fuel briquettes from biomass

The project implemented in 2010 is the result of a collaboration between the Virunga National Park (PNVi), the Congolese Institute for the Conservation of Nature (ICCN) and the Environment, Natural Resources and Development Network (ERND), who are popularising briquettes called 'makala ya sasa' (meaning new embers in Kiswahili) as an alternative to the use of firewood and embers. Biomass briquettes are made from leaves, bark and peel of fruit or other agricultural waste such as rice, beans,[4]maize, sugar cane, etc. The briquettes are made from the leaves, bark and peel of fruit or other agricultural waste such as rice, beans, maize, sugar cane, etc. The briquettes are made from the leaves, bark and peel of fruit or other agricultural waste such as rice, beans, maize, sugar cane.

3.2.4.1.1. Challenges

The main challenges related to this project are :

1- Non-membership of charcoal sellers
2- Difficulties in accessing financing

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[3] *https://www.ga.undp.org/content/gabon/fr/home/projects/projet-recuperation-des-dechets-agricoles-et-forestiers-pour-une-energie-durable.html*
[4] *http://www.reseau-cicle.org/wp-content/uploads/riaed/article_PDF/article_2660.pdf*

3.2.4.1.2. Lessons Learned

The gap analysis report in relation to the objectives of the "Global Initiative for Sustainable Energy for All" (SE4ALL, 2030) carried out by UNDP in 2013, draws up an exhaustive assessment of the forest fuel issue in DRC and anticipates all the concerns raised by the Call for Expression of Interest, particularly on the urgency of initiating wood energy substitution programmes, while drawing up a summary but fairly complete inventory of the situation in DRC for each of the possible solutions;

3.2.5. Congo Republic

3.2.5.1. Installation of a biomass and cogeneration plant

The production of electricity from a cogeneration plant in the departments of Niari, Lékoumou and Bouenza is a development project deemed profitable by the PRONAR feasibility study which defines a production capacity of 4 MW electric and 25 MW thermal from 99,692 m^3 of raw wood. The biomass used can come from plantations to be considered with eucalyptus clones at a planting rate of 738 ha/year and from the valorization of wood industry waste.

The cost of the project is estimated at CFA F 9,839,355,000, or USD 17,700,000.[5]

3.2.5.1.1. Challenges

Collection and transport of biomass from the production sites to the processing site.

Investors who are very reluctant to invest in financing

3.2.5.1.2. Lessons Learned

The government encourages and supports independent power producers.

3.2.6. Central African Republic (CAR)

The PARIS-CONGO project is a project located in the prefecture of Lobaye. The 1000 inhabitants who live in this locality use biomass as an energy source. The Paris-Congo project will use the pulp as a source of energy. From hulling coffee to produce electricity. The project evaluates the production of parthèses at 120 tons per year with a caloric value of 300 MJ and an energy production of around 500Mwh.

3.2.6.1. Challenges

The main challenge for the implementation of this project is access to funding.

[5] *https://apicongo.org/projets_prives.php*

3.3. West Africa

3.3.1. Senegal

3.3.1.1. BRADES Project, St. Louis, Senegal

The BRADES (Bureau de Recherche/Action pour le Dèveloppement Solidaire) company was established as a family business in 2007 by Mr Nthiè Diarra, who is also the current chairman (Douard, Brades, biochar producer in St Louis, Senegal, receives the SEED award, 2012). The main business of the company is manufacture and marketing of biochar made from coal and clay, which are compacted by an electric machine known as the Rotor Press. The company is headquartered in St Louis. The raw charcoal and clay are collected in the vicinity of the company's headquarters where they are then mixed with water before compacting them into rods using the Rotor Press. The Rotor Press has an hourly output of 60kg of biochar. The biochar is put on shelves to dry for 3 days. After the three days, women come and collect the biochar using reused cement bags for resale to the company or to the market. Between 2007 and 2013, the company produced an estimated 400 tonnes of biochar (Diarra, n.d).

The company has teamed with other players to provide support financially, technically and in supplies of raw material. GIZ, through its Programme for the promotion of renewable energy, energy efficiency and access to energy services (PERACOD) in Senegal, provides educational and technical assistance. The Crédit Mutuel du Sénégal (CMS) provided a loan while the Union of Forest Operators of Senegal provides the raw materials (Douard, Brades, biochar producer in St Louis, Senegal, receives the SEED award, 2012). The main objective of BRADES is to provide alternative sources of household energy which are cleaner and preserve the forests of Senegal from deforestation (BRADES, n.d).

3.3.1.1.1. Challenges

1. The company had to overcome the bad reputation of biochar among the general population that had emanated from past experiments.
2. Many rural areas in Senegal are still inaccessible, and this poses a transport barrier to potential markets in these areas that still rely on charcoal and firewood.
3. Locally produced charcoal still poses a high competition where the population is more familiar to it than the biochar.

3.3.1.1.2. Lessons Learnt

1. To overcome negative perceptions on biochar, BRADES conducted demonstration forums with Women's Groups to compare the product against charcoal. The Women's Groups were allowed to test out the products within their households. This was a practical way to create awareness and allow the local population to ascertain the benefits independently.
2. Strategic advertisement of the biochar product was conducted at the charcoal sale points. This created awareness of an alternative cooking fuel to a larger population who converge at the market than if individual promotion was done.
3. New individual points of sale were identified after the strategic advertising explained above. The individual points of sale are established when a group of people identify a new site that will act as the selling point of biochar. These new selling establishments are a sign that the community is gaining interest in purchasing the biochar.
4. Optimization of briquetting using technology reduces labour costs while increasing the production efficiency. To keep the efficiency stable, a wide base of raw material supply should be considered to compensate for the "idle" moments, when briquettes are left in the sun for days to dry. In the case of BRADES, women and local groups provide the raw material (BRADES, n.d).

5. As a Corporate Social Responsibility (CSR), the company allocates 10% of its profits to reforesting the downstream section of River Senegal. This helps BRADES gain recognition and potential support from both governmental and non-governmental bodies (NGOs).

3.3.1.2. FASEN Project, Senegal

PERACOD, an initiative of GIZ, started a program known as Improved Stoves in Senegal (FASEN) to increase the accessibility of rural households to cleaner cooking fuels. FASEN collaborates with artisans, blacksmiths and distributors such as Women's Groups and shopkeepers to produce and market improved cooking stoves at large scale (Menet, 2015). In Senegal, the programme plans to reach 150, 000 people in the regions of Fartick, Kaffrine, and Diourbel (Douard, West Africa Cooking Energy Program, 2012). BISS and PERACOD merged to provide better ecological cooking technology and boost distribution efforts. The improved cooking stove is a product of clay and ceramic inserted in the interior and is cheaper than the CBE type rocket stove (Menet, 2015). The partnership of BISS and PERACOD in Senegal aims to support the Consultative Council of Women of Djiofor (CCFD) with cooking stoves. The CCFD will in turn establish a fund and marketing approach to earn revenue from the sale of stoves. The group is also responsible in training artisans and blacksmiths in manufacture of the improved cooking stoves. The PERACOD activities in Senegal are part of a wider program known as the Program for Economic Cooking Energy in West Africa **(**ProCEAO) which aims to provide sustainable wood energy to the West African Region. The countries included in the project are Benin, Senegal, Burkina Faso and Mauritannia. The program was launched in March 19th, 2020 and was expected to run until December 2014 (Douard, West Africa Cooking Energy Program, 2012).

3.3.1.2.1. Challenges

1. Weak revenues of households in rural settings, which limits the spread to these zones.
2. Weak capacity for manufacturing ceramic inserts for some models, in good number & quality.
3. Difficult traceability of the stoves (time of use, life span…); which hinders access to carbon finance.

3.3.1.2.2. Lessons Learnt

1. Adaptability of the stoves to the cooking methods will improve adoption in the target community. The FASEN stoves are designed to accommodate various cooking methods, pots and design preferences to be taken up by a wide range of Senegalese households (Menet, 2015).
2. A marketable approach will cover most of the expenses. In the case of the FASEN project, the stoves are sold without price subsidy, which means that all the manufacturing costs will be catered for by the customer.
3. Cooperation with local artisanal groups minimizes the use of expensive material that ultimately increases the buying price of the stoves. Considering that most artisanal groups are informal, collaborating with them necessitates the use of locally available materials such as clay and ceramic which do not inflate the final price of the stoves.

3.3.2. Burkina Faso

3.3.2.1. German NGO Atmosf'air Project: Gasification using crop residues at Pô, Burkina Faso

Pô is a town of 53, 000 inhabitants located in southern Bukina Faso (Slate Africa, 2015). Farmers who live in the vicinity of the main hospital at Pô bring their cotton and sisal stalks to the town hall at the end of every harvest season. The agricultural residues, which may also include millet, sorghum and peanut shells are weighed by staff trained by Atmosf'air, a German firm. The agricultural residues are weighed and the farmers paid at the rate of 10CFA per kg (which translates to 10, 000 francs per ton or roughly 10 euros). The agricultural residues are dried for several days before being fed into the gasifier machine. Around 600kg of agricultural residues can be delivered per day after harvest period (Slate Africa, 2015). The gasifier needs an hourly supply of 30 to 40 kg of biomass to generate 22kW/h, which powers the hospitals emergency services during power cuts. Even though the gasifier saves 30 to 40 % of the hospital's electricity bill, it is not able to power all the hospital's equipment at the same time. Within six months, a gasifier with a capacity of 250kW/h was expected to take over from the current 22kw/h machine (Slate Africa, 2015).

3.3.2.1.1. Challenges

1. The national electricity provider (Solanebo) did not give approval for the project, despite the benefits that the community would gain. Though the project is functioning, no commercial operation is allowed for the gasifier installed at the hospital in Pô region (IKI, 2020).
2. Because the gasifier runs on biomass, there is a likelihood for a shortage of agricultural residues to occur during dry periods. The country is considered one of the most vulnerable to climate vagaries that affect food security. Less than normal rain will most likely affect quantities of harvest, and consequently, the amount of agricultural residues that remain.

3.3.2.1.2. Lessons Learnt

1. Legislation can be a supporting means or a barrier to mini grid projects depending on how they are used. For governments that are aware of the inability of the national utility to universally provide electricity to its population, it is preferable for the administration to create a conducive environment for third parties to step in and ameliorate the energy situation rather than hinder as the case of Burkina Faso shows.

3.3.2.2. FAFASO project in Burkina Faso

Beer brewing is the third most important economic activity in Burkina Faso after farming and wage labour. The beer making industry employs about 25, 000 people nationally even though it is majorly informal and traditional. The breweries are concentrated in the two largest cities of Ougadougou and Bobo-Dioulasso, each having an estimated 2380 and 1144 breweries respectively (GIZ, 2013). Brewing is an intensive thermal input process, and is one of the highest consumers of firewood in Burkina Faso. In Ougadougou alone, the brewery industry consumes about 50% of the total firewood consumption. The objective of Foyers Améliorés au Burkina Faso (FAFASO) which literally means "Reducing Poverty through Energy Efficiency and Renewable Energies" provides improved cookstoves to households and institutions to reduce use of traditional cooking-fuels. The project provides metallic stoves to households but for the beer brewers, bigger mud-stoves are built. The goal of FAFASO was to manufacture 2000 mud-stoves for the beer industry in a two-year period that was to end in 2012. Surprisingly, this was exceeded when 2200 were built at the end of the project period in December 2012. The improved cookstoves use CFA 2500 (USD 5) on firewood compared to CFA 7500 (USD 15) with a traditional stove. This enables beer makers to earn more profit from their brewing activities. By percentage, the FAFASO mud stoves have 60% and 80% more efficiency than the traditional stoves and three-stone hearths respectively which are still in use for brewery in the rural areas (GIZ, 2013).

3.3.2.2.1. Challenges

1. Lack of awareness and poverty are the main hindrances to the uptake of cleaner cooking technologies. The local households may not have the capital to purchase the stoves, except for the brewers. Enhanced awareness is also needed to shift the mindset of the population to using improved cookstoves.

3.3.2.2.2. Lessons Learnt

1. The product must be visible and recognizable through a logo. TV and radio are good diffusion means.
2. Marketing campaign must be undertaken just at the same time that the ICS are available, and marketing actions must be done only when you are sure that you have enough ICS stocks; only to avoid too much not-fulfilled expectation.

3.3.2.3. Cajouvalor Project in Burkina Faso

The Cajouvalor project aimed to set up several pyrolysis units across Burkina Faso. One was installed at the Hauts Bassins region and the other at Gebana in Bobo Dioulasso region (Agencie Ecofin, 2012; Nitidae, n.d). The pyrolyzing machines convert cashew nut shells into charcoal, thus increasing their value while also providing energy to run the pyrolyzer unit. The pyrolyzer oven processes 200kg of hulls per day to produce 30kg of hull charcoal (Agencie Ecofin, 2012). However, about two tonnes of raw nuts are processed in Gebana on a daily basis, which may not include those subjected to pyrolysis. The Cajouvalor program estimates that it reduces 50% of biomass that would have been used, and an equivalent amount of CO_2 that would have been released into the atmosphere (Nitidae, n.d). The project at the Hauts Bassins region started in January 2011, and was completed in December 2014 at a cost of 205, 000 euros. The Centre Francophone de Recherche Partenariale (CEPERFADE) was a contributing partner in both of these projects. However, no electricity at the moment can be generated from cashew nut shells.

3.3.2.3.1. Challenges

1. When cashew nuts are burnt, the phenolic oil in the shells produces acid fumes that are both polluting and irritating. The Cajouvalor project aims to ameliorate this hazard.

3.3.2.3.2. Lessons Learnt

1. Biomass projects are considered valuable in their transformation of waste products to a commercial product. In the case of the Cajouvalor project, cashew-nut shells that would have ended up as waste are revalued by transforming them into biochar. According to the energypedia site, the pyrolysis gas and biochar produced can be used in other small scale purposes such as mango drying, in cotton oil factories and local soap producers (Energypedia, 2020).

3.3.3.Benin

3.3.3.1. ProCGRN providing Improved Cookstoves for Shea Butter Producers in Benin

Shea butter is the third most important revenue source in Benin. It comes after cotton and cashew nuts. The district of Atacora in Northern Benin is one such producer, but has suffered extensive deforestation to meet the energy needs of the rapidly growing population. The Programme of Management and Conservation of Natural Resources (ProCGRN) under the auspices of Energizing Development (EnDev) program (GIZ, 2013) set out to provide Improved Cookstoves (ICSs) to the shea butter producers to reduce the amount of firewood used. The rate of deforestation is expected to reduce in the process. In addition to providing cookstoves, ProCGRN also offered technical and business training to the stove producers to spur the local economy.

The stove type that was being distributed is the “fixed rocket mud stove”. The stove is made of clay, and a mixture of organic material such as dry grass and chopped banana leaves. The hole for placing the pot is at the top while at the bottom there is an inlet for placing the firewood. The mud stove is bigger than the conventional metallic stove. However, this stove saves 50% of firewood used compared to the three stone hearth. The rocket mud stove costs CFA 5000 and 7000 (USD 10 -15) and considering three cooking sessions per day, the mud stove saves CFA 1050 (USD 2.10) on firewood (GIZ, 2013). The duration of this project was from September 2009 to December 2014.

3.3.3.1.1. Challenges

1. Considering that the stove is made of clay and other organic material, structural stability of the stove is a concern in case of adverse weather such heavy rainfall or high impact hits.
2. The fixed rocket mud stove is built from the ground up and is thus immovable. Once fixed on the ground, it cannot be moved unless it is first destroyed. From a skeptical approach, it does not also save much on forests since the fuel input is raw firewood that has not undergone any conversion or value-addition to other forms such as briquettes to improve on its energy efficiency.

3.3.3.1.2. Lessons Learnt

1. If innovation is applied, freely available local materials can be used to create a product that has superior energy efficiency compared to conventional cooking methods. The rocket stove is made of organic materials that can be collected on the field, yet it is considered to save fuelwood amounts by 50%.
2. Identification of the industries that contribute to deforestation will help in narrowing down to the actors responsible. In the case of ProCGRN, helping the shea oil producers with improved stoves reduces their frequency of cutting down woody biomass at household level, while at large scale it cumulatively reduces the number of trees and woody biomass cut down both spatially and temporally.

3.3.4.Mali

3.3.4.1. Foyers Améliorés au Mali (FAMALI)

FAMALI was a GIZ project in Mali that aimed to disseminate improved household stoves to Bamako, Ségou and Sikasso towns in Mali. The objective was to disseminate 15,000 stoves to a population of 90, 000 people (Gaul, 2009). This population took to account an average family size of 6 people. This project was jointly implemented with FAFASO project in Burkina Faso. The first phase of this project ran from September 2005 to June 2007 (*Ibid)*. The FAMALI project aimed to set up base in Mali and produce the improved stove models. The stove models were Sewa, Teliwan, and Nafacaman(Ibid). The three phases of the project involved the following activities (GTZ, n.d):

1. Technical training of blacksmiths for stove production and increasing demand through public relations and project-based marketing.
2. Organizations of the producers to associations or cooperatives, and a management team to take over the marketing.
3. Consolidation and extension of the supply base through creation of new associations in all regions.

Sustainable production of the improved stoves was the long-term objective of GTZ while upgrading the artisans was considered secondary. The first objective seems to have been met, since there have been many improved stove projects in Mali and thus there is still a potential market for this product.

3.3.4.1.1. Challenges

1. There were other existing similar projects of improved stoves in Mali before the entry of the GTZ. These were PEDASB (French abbreviation for the World Bank HEURA Project) and PREDAS (Regional Program for Household Energy Promotion in Sahel Coutries), the former being in conjunction with the local Malian agency AMADER (Malian Energy Agency/Agence Malienne pour le Développemnet de l’Energie Domestique et de l'Electrification Rurale) (Gaul, 2009). The local AMADER project perceived the entry of GTZ as an unhealthy competitor.
2. There was heavy bureaucracy in Mali where simple decisions were subjected to long red tape.
3. It was difficult to get the raw materials for manufacturing the improved stoves since all the three models were made of metal with Sewa having ceramic as an added material.

4. The project was not receiving pay-back for its investments. Report by Gaul (2009) seems to suggest achieving sustainability of the project was a problem. This is in contrast to the PEDASB project that was receiving funds from the World Bank to finance its operations.
5. Since the improved stoves are made of metal, any increase in the price of metals will make the stoves beyond the affordable reach of many rural Malian households.

3.3.4.1.2. Lessons Learnt

According to Gaul (2009) these were some of the recommendations:

1. Regular meetings between producers, promoters and retailers are important for evaluation and quantifying progress.
2. Training of producers to be based on social surveys in the region.
3. Business plans should be established for each producer.
4. It is recommended a marketing expert to oversee the contracted producers on a day-to-day basis. This can be associated with the need to establish a large customer base to retrieve pay-back for investments as fast as possible.

3.3.4.2. ALTERRE Project in Mali

The ALTERRE project has been operating in Mali since 2009. The projects' aim was to set up a unit that would process Jatropha seeds to Jatropha Vegetable Oil. The latter would be used as an alternative to diesel in powering the milling machines. The ALTERRE's project focus was on three regions; the municipality of Yorosso, the municipality of Koury and the 13 villages spread over the municipalities of Konseguela and Diedougou (GERES, 2016; Solar Synergy, 2020; GERES, 2019). All these territories are located in the south-eastern of the country. Local Jatropha oil processors were installed in each project site.

The Jatropha agrofuel processors will be supported by solar power panels to provide energy to the surrounding communities. There has been some partial success in the village of Konseguela, located 50 km east of Bamako. In 2013, the Sub-Prefect (an administrator) of Konseguela/Diedougou provided the ALTERRE project with land to set up a micro-electrified Activity Zone (ZAE) at the edge of the district (GERES, 2016; GERES, 2019). The ZAE was to be a local economic zone powered by solar power and Jatropha oil generators. Approximately 3800 households would positively benefit from this project. In addition, the ALTERRE project will introduce new industries to the villages such as internet services, wielding, baking and revival of over 80% of the milling machines that were shut down between 2008 and 2013 due to high diesel costs (GERES, 2016). The preparatory phase began in 2014, the project launch took place in November 2014 and was to run until 2016. Phase 2 of the project began in March 2017. Within the same year, a solar plant was set up and a meter billing system installed for the electricity customers.

3.3.4.2.1. Challenges

1. Due to financial constraints and high capital expenditure required, donor funding was a critical support to complete each of the project's phases. In the GERES website, a total of 35,000 Euros had been donated within a span of two years by 2016.

3.3.4.2.2. Lessons Learnt

1. In addition to the biomass conversion, the project also harnessed solar energy to ensure sustainable supply of power.
2. Local support is crucial for any project. The Sub-Prefect, after noticing the advantages of the ALTERRES project, proceeded to guarantee them land to set up the solar panel plant.

3.3.5.Côte d'Ivoire

3.3.5.1. Agrovalor Project in Côte d'Ivoire

The Agrovalor project partnered with the French Aid Agency (AFD) and other cooperations to distribute agro-industrial energy recovering equipment to the northern regions of Côte d'Ivoire. The target towns were Bouakè and Korhogo (Nitidae, n.d). The energy recovery equipment will be distributed according to the agricultural product harvested at the site. Three agricultural products were identified namely cashew nut shells, Shea and Cassava waste. The direct beneficiaries would be the associations involved in the production of these products while the women and other employees of these associations would be the indirect beneficiaries. The project commenced on December 2017 and completion is set for June 2021. The total costs of the project amount to 800,000 Euros (Nitidae, n.d). So far, eight cashew nut processing groups have been handed the pyrolysis machines. Training was conducted for each of the beneficiaries.

The High Calorific Cashew Pyrolyser (H2CP) machine heats up the cashew nut shells injected into the oven to temperatures of 1000°C in the absence of oxygen. In the absence of oxygen, the cashew nut shells turn into biochar while the poisonous lining of the cashew nut shells is liberated from its chemical bonds to form pyrolysis gas. This pyrolysis gas is taken downstream of the oven where it combines with oxygen to provide thermal energy (Nitidae, n.d).

3.3.5.1.1. Challenges

1. The northern areas of Côte d'Ivoire, which are the main cashew nut producing zones, face insecurity threats from government rebels. More than 54% of the cashew nut producing areas (Kone, 2010) are located in these risky areas.

3.3.5.1.2. Lessons Learnt

1. Apart from energy production, an environmental perspective can be the source of an innovative agrowaste processing equipment. The Agrovalor project repurposes the agro-industrial waste of not only cashew nut shells, but also cassava and other residues into a new form that minimizes soil pollution. The H2CP pyrolyzers prevent the release of a poisonous chemical called phenolin from untreated cashew nut waste.

2. Waste forest biomass availability in specific countries

In this section, we synthetize the findings in 2.1 and 2.2 and undertake an assessment of the potential of specific resources, sites and actors in each country. This assessment and following recommendations will be matched with assessments from Deliverable 3.1 and 3.2 to derive a Technical feasibility analysis in Deliverable 3.3.

4.1 Estimates residues in the national forest stock of study Countries

Multiplying the percentage of residues available in a single tree (50%) by the tonnes of biomass in a country's productive forest will give a reasonable estimate of the stock of residues in a given forest mass. The table below shows the results of the analysis, listing the total residue stocks in productive forests for all countries in the sample.

Table 3: Estimated residues from the national forest stock

Country/Region	Forest area (1000 ha)	Potential residues in the productive forest stock, 46% of the total stock
Benin	3135.15	1442,169
Burkina Faso	6616.5	3043,59
Ivory Coast	2518	1158,28
Senegal	8068.1	3711,326
Togo	195.90	90,114
Mali	13296	6116,16
Burundi	279.64	128,6344
Djibouti	5.80	2,668
Cameroon	20340.4	9356,584
Chad	4313	1983,98
Congo	21946	10095,16
DRC	126155	58031,3
Gabon	23530	10823,8
Guinea Eq.	2448	1126,08
Rep.Centrafri.	22303	10259,38

Source: Calculations using FAO data (2020).

This estimate remains theoretical and does not take into account at this level that, among the forests identified, some areas may be inaccessible to exploitation (steep slopes, wetlands, protected areas, local use areas). Moreover, the forest does not necessarily represent an interest for exploitation.

4.1.1 Estimated total residue production

This sub-section assesses the amount of residues available for energy use.

4.1.1.1 Results based on industrial roundwood production

According to FAO (2011), industrial roundwood is used for purposes other than energy. It includes pulpwood for paper; saw logs and veneer logs for construction and furniture; and other industrial roundwood (e.g. fence posts and telegraph poles). Industrial roundwood will be a product of the section of the tree trunk and contains the source of most sawmill residues. Sawmill residues are easily derived from the blue section of the table in the figure above, but as mentioned above, excludes waste left in the forest from the initial felling and cutting (e.g. tops, branches, foliage, sawdust and stumps). For FAOSTAT, it is reported in cubic meters of solid volume under bark (i.e. excluding bark) (FAO, 2010).

The amount of crop residues that plantations could produce for bioenergy production is directly related to the usable volume of wood from the plantations. In order to quantify the potential volume of crop residues that could be generated annually by plantations, the simple allometric formulas presented above and developed by Dovey (2005) for estimating crop residues of various wood species were used in combination with the projected annual usable wood volume table.
The estimate of the potential for available sawmill scrap wood was made by taking into account the following data: volume of logs entering the mill; sawmill production; material yield; gross volume of sawmill scrap wood; carbonizable volume after deduction of intermediate recoveries made.

The Potential Residue Supply uses the latest data on industrial roundwood production from FAO. Where forest biomass is reported in tonnes, roundwood production is reported in volume units (1,000 m^3). Residues from annual roundwood production can be estimated using the following approaches:

- FAO global and national roundwood production is expressed in 1000 m^3 (2013); the volume of roundwood (1000 m3) in mass (tonnes) is converted using average densities as follows: 700 kg / m3 for coniferous species and 756 kg / m^3 for non-coniferous species.

- During the timber production process, only 28% of the tree is recovered for sawn timber products and 17% for smaller sections such as slabs, curbs and off-cuts, the original purpose for which the tree was originally intended.

- The total residue potential per tonne of roundwood is then determined by adding to the sawmill residues that would have been produced during felling.

Table 4: Expected yield of forest harvest residues in year

Country	Domestic log production (1000 m^3)	Industrial roundwood production *, Mt	Logging and Forest Cutting Residues, Mt	Sawmill residues, Mt	Total Residue Potential from Industrial Wood Production, ** Mt
Benin	150,014	0,10	0,05	0,02	0,07
Burundi (2018)	318	0,23	0,13	0,05	0,18
Cameroon (2014)	2 747 38,0	192,3	103,8	39,8	143,6
Congo (2018)	1 831 74,6	128,2	69,2	26,5	95,7
Ivory Coast	1554,013	1,08	0,57	0,22	0,79
Gabon (2014)	1 705 15,0	119,3	64,4	24,7	88,9
Guinea Eq (2010)	309 84,8	21,6	11,6	4,5	16,1

Mali (2015-2017)	50,640	0,03	0,01	0,009	0,01
DRC (2014)	289 163	202,4	109,2	41,8	151
RCA (2014)	237489	166,2	89,7	34,4	124,1
Togo (2015-2017)	56,312	0,02	0,01	0,004	0,01
Total	**239617,979**	**831,46**	**448,67**	**172,003**	**620,46**

* derived from industrial roundwood production data (adjusted for softwood/non-softwood roundwood)

** excludes losses, sawn wood, edges and sawdust

Source: Authors' calculations

It is best to interpret the above table using a country example. In 2014, the largest producer of industrial roundwood was the DRC with a production of 202.4 Mt / year (289.163 million m3). Cutting and shaping of roundwood gives an estimated level of residues and waste of 41.8 Mt / year. A large amount of residues is produced at the logging stage and could represent 109.2 Mt / year; the combined total of logging and sawmill residues amounts to 151 Mt / year. The potential residue to be produced by the DRC is 151 Mt / year. This means that with effective recovery, even with some losses, more than 151 Mt / year of wood residues and waste from roundwood production could be used as renewable fuel.

These calculations will also be made for all countries producing industrial wood as soon as data are available.

Central Africa is the region with the most abundant forest biomass with vast areas of tropical forest, including 245,341 million hectares of biomass stock. Tonnes per hectare for tropical forests in Central Africa are significantly higher than for western and eastern African countries. The combination of large areas and very dense biomass forest is due to high rainfall and excellent growing conditions for tropical tree species. Immediate available sources of biomass residue can be found in the following countries:

4.2.1.Cameroon

Cameroon has approximately 86,532 million hectares of forest which are managed for the production of wood and non-wood forest products, representing 28% of the total forest area. Most of the production forests are concentrated in Eastern Cameroon. One might think that this Region has, in fact, the greatest potential for logging residues. Cameroon's log production remains more or less constant, thanks in particular to the diversity of its production, which enables it to cope with market fluctuations more easily than forest massifs heavily dependent on one or a few species. This also implies consistency in the availability of logging residues. The total residues potentially available by forest title in 2013 was over 1.2 Million meterscubed in Cameroon.[6] Additionally, there are about 203 Raw Wood Processing Units (WPU) for processing of raw wood into various products (including sawn timber, veneers, plywood, furniture, etc.). In 2015 the estimated carbonizable residue potential in all the sawmills in Cameroon was 528, 378 meters cubed. The map below shows the location of these WPUs in Cameroon, note that most of them are towards central and Eastern side.

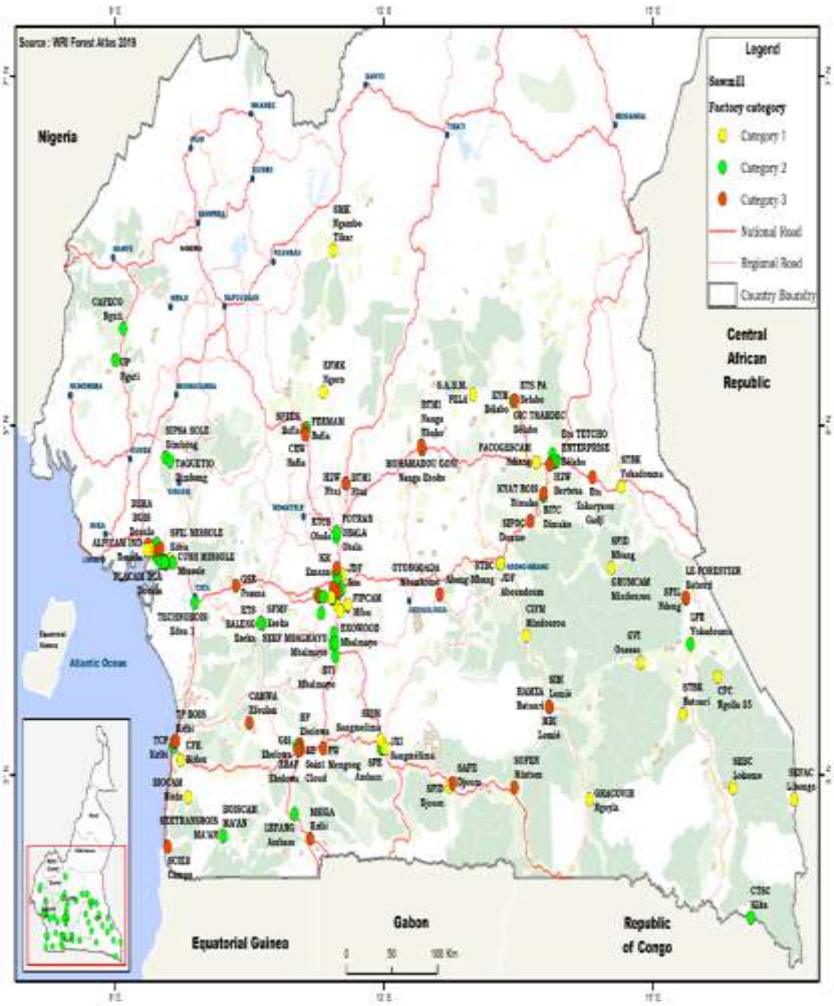

Figure 8: Map of logging and wood processing centres in Cameroon

[6] https://www.observatoirecomifac.net/monitoring_system/national_indicators?year=2020&country=CMR&step=3

4.2.2.Republic of Congo

Nearly 75% of the Congolese forest, that is, more than 15 million hectares, belongs to the production forest estate, including 14.4 million hectares currently allocated as forest concessions. Logging is conditional on obtaining logging permits. _The average area allocated per operator is nearly 400,000 ha, with strong disparities. Concessions in Northern Congo are larger than those in the South. Sixty two (62) forest concessions in the Republic of Congo are exploited by 35 logging and industrial companies. In 2018, these companies produced **1,831,746.52 m^3,** or a potential **842,603.40 m^3 of residues (which includes 242,558.75m3 of sawn timber, 45,352.68m3 peeled veneer and 8,064.43m3 of plywood.** WPUs include sawmills; 12 drying units; 6 peeling units; 5 plywood units; 1 slicing unit; 2 high-capacity industrial joinery mills; 2 medium-capacity industrial joineries; glued laminated units; 1 parquet flooring unit; 1 moulding unit; 2 cogeneration units; 1 impregnated wood unit; 1 eucalyptus chip production unit;The map below shows the spatial distribution of production forests and the 61 wood-processing units of all types. Details of logging companies is annexed.

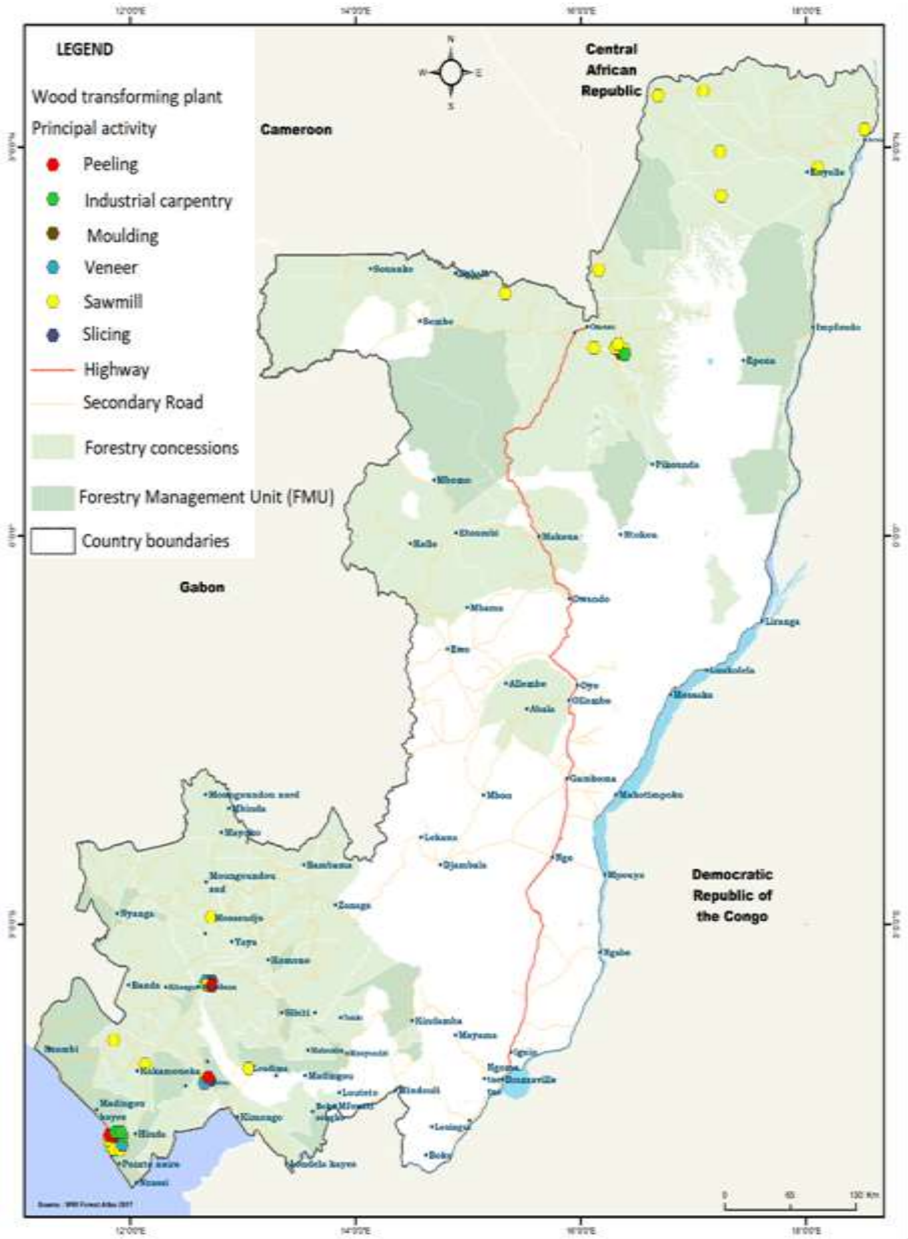

Figure 9: Map of Forest concessions and wood processing units in Congo

4.2.3. Democratic Republic of Congo

Eight of DRC's 26 provinces contain forests for industrial logging, that is, Ituri, Kasai, Equateur, Maï-Ndombe, Mongala, Shuapa, Tshopo and South-Ubangi provinces. These eight form a privileged basin for the supply of wood for international and national markets. There are a total of 57 forest concession titles which cover an area of approximately 10,715,678 hectares. The Tshopo, Equateur and Maï-Nombe provinces alone contain 71% of the forest concession contracts granted by the Congolese state to companies, with the remaining 29% divided among the five remaining provinces.

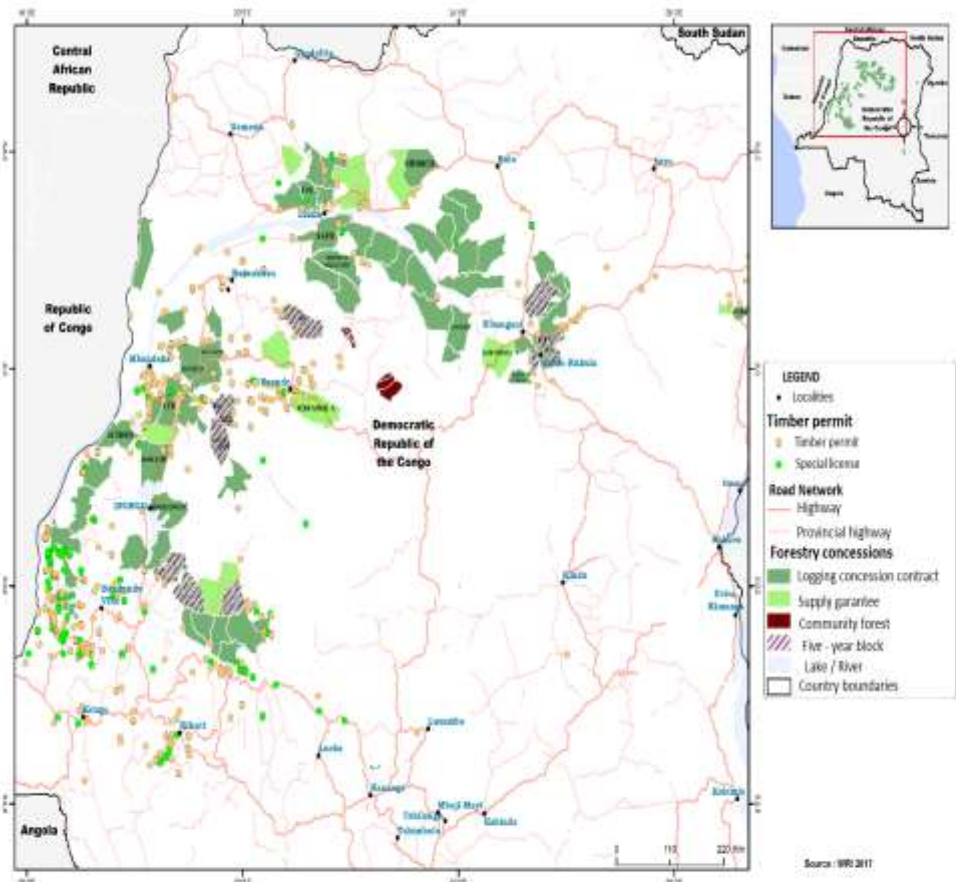

Figure 10: Map of Forest concession areas and logging permits in the Democratic Republic of Congo

Table 5: Geographical Distribution of Forest Concession Contracts in 2019

Province	Number of Forest Title	Area
Tshopo	14	2 957 661
Mai-ndombe	16	2 635 520
Equator	12	1 939626
Mongala	7	1 258 217
Mai-ndombe/Equateur	2	569 517
Mongala/Tshuapa	2	499 643
Equator/South Ubangi	1	284 323
Tshuapa	1	275 064
Ituri	1	60 182
Kasai	1	13 925

Total	57	10 715 678

Source: Quarterly Report of 31 May 2019 AGEDUFOR

The map below gives an overview of the location of the different logging permits and logging concessions.

The **Wood processing units or Sawmills are not very well** developed as companies limit themselves much more to primary processing in order to produce edged or sliced sawn timber and peeled veneers. Both secondary and tertiary processing are extremely rare. (https://www.institut-numerique.org/12-transformation-du-bois-en-rdc-52f090366f16a). The table below shows the most potential WPUs for bioenergy residues production and their location.

Table 6: The different Wood Processing Units (WPUs) and their production capacity

Company	Location	Type of products	Capacity m^3
SODEFOR	Nioki and Kinshasa	Edged sawing & trenching and plating unfolded	From 30 000 to 40 000
COMPAGNIE des BOIS	Oshwe and Kinshasa	Edged sawing and peeled veneer	From 2 000 to 6 000
FORABOLA	Congo central	Edged sawing and Peeled veneer	From 20 000 to 10 000
SIFORCO	Kinshasa	Edged sawing and Peeled veneer	10 000 à 12 000
IFCO	Kinshasa	Sciage + parquet, lambris	24,000 (i.e. 2,000 per month)
CFT	PK9 R Bangoka	Edged sawing and Peeled veneer	30 000
MOTEMA	Kinshasa	Sciage	63 397
SCIBOIS	Equateur	Sciage	18 000

4.2.4. Gabon

There are one hundred and sixty-two (162) logging and industrial companies in Gabon. The Estuary Province alone has 76 wood processing units with sawing and veneer as the main transformation. The Ougooué Lolo and Ougooué Maritime regions each hold 9 WPUs. **Table below shows distribution of the different logging titles for the year 2019.** In 2011 CFAD production was 1,410,949 m^3 with potential wastes 649 036.54 m^3 · CPAE 186 940 m^3 85 992.4m^3

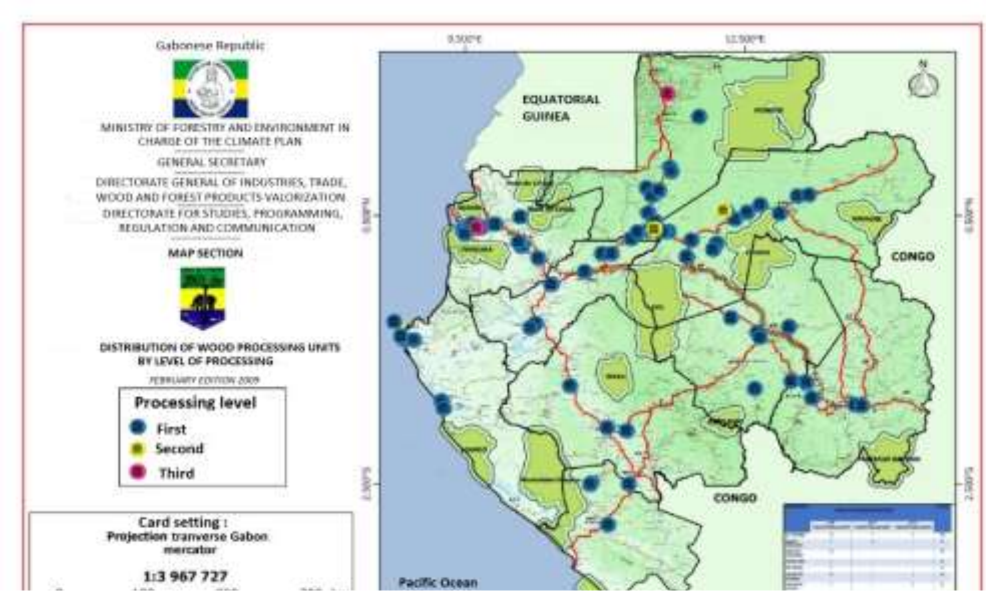

Figure 11: Location of Wood Processing Units (WPUs) in Gabon

Source : [https://www.observatoire comifac.net/monitoring_system/national_indicators?year=2020&country=GAB&step =3](https://www.observatoire-comifac.net/monitoring_system/national_indicators?year=2020&country=GAB&step=3)

Table 7: Distribution of the different logging titles for the year in 2019 Gabon

Forestry Permits	Number	Area GIS Km²
CFAD	56	98 609.48
PFA	26	3 816.94
CPAE	46	50 915.07
Forêts Communautaires	13	580.25

Source :

4.2.5. Central African Republic

In CAR, logging titles are called Operating and Development Permit (PEA) and they grant the right to operate with industrial means, subject to compliance with national laws and regulations. In 2016, out of 14 PEAs allocated, nine were operational, three were dormant and two were newly allocated. In addition to the PEAs, 16 artisanal permits were granted from 2010 to 2016.[7]) The map below shows the location of the various operating permits in the CAR.

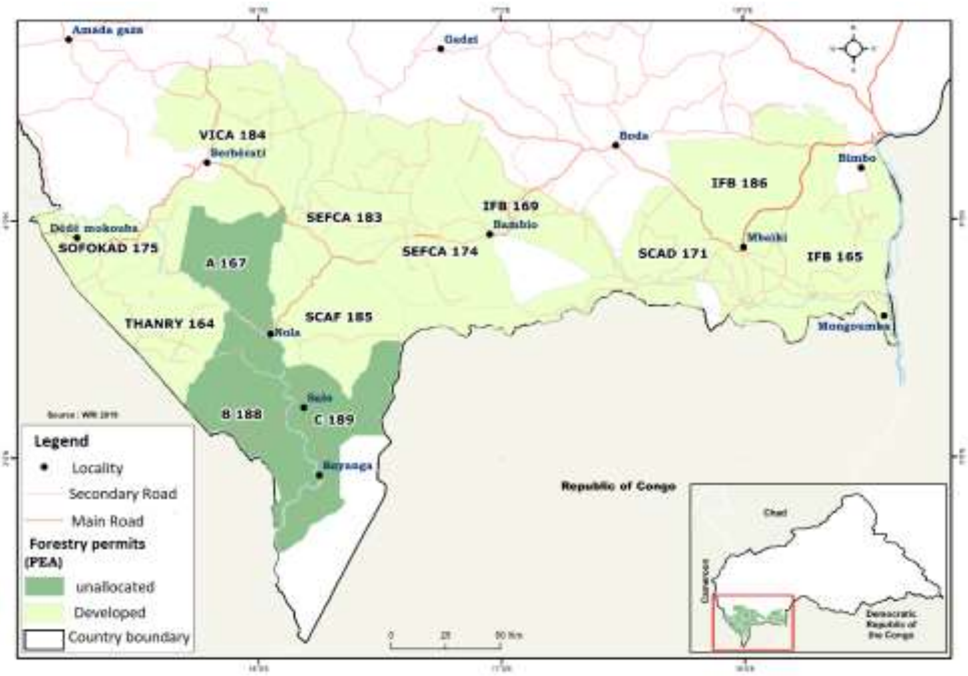

Figure 12: Location of the different operating licences in Central African Republic

b) **(Sawmills)**

Ten WPUs were identified in the CAR. The table below summarizes them by type of activity.

Table 8: Wood processing units by type of activities in Central African Republic

Company	Type of activity	Year	Capacity m³
SOFOKAD	sawmill	1970	3 800
THANRY	sawmill	1998	600
SCAD Loko	Sawmill, peeling	1950	1 875
SCAD Ndolobo	sawmill	1967	2 917
IFB Ngotto	sawmill	2005	700
SEFCA	sawmill	2005	0
SEFCA	sawmill	1995	10 000
SCAF	sawmill	2001	4 500
IFB Batalimo	sawmill	1997	5 500
SCD	mobile saw	2010	450

[7] http://www.fao.org/3/I8596FR/i8596fr.pdf

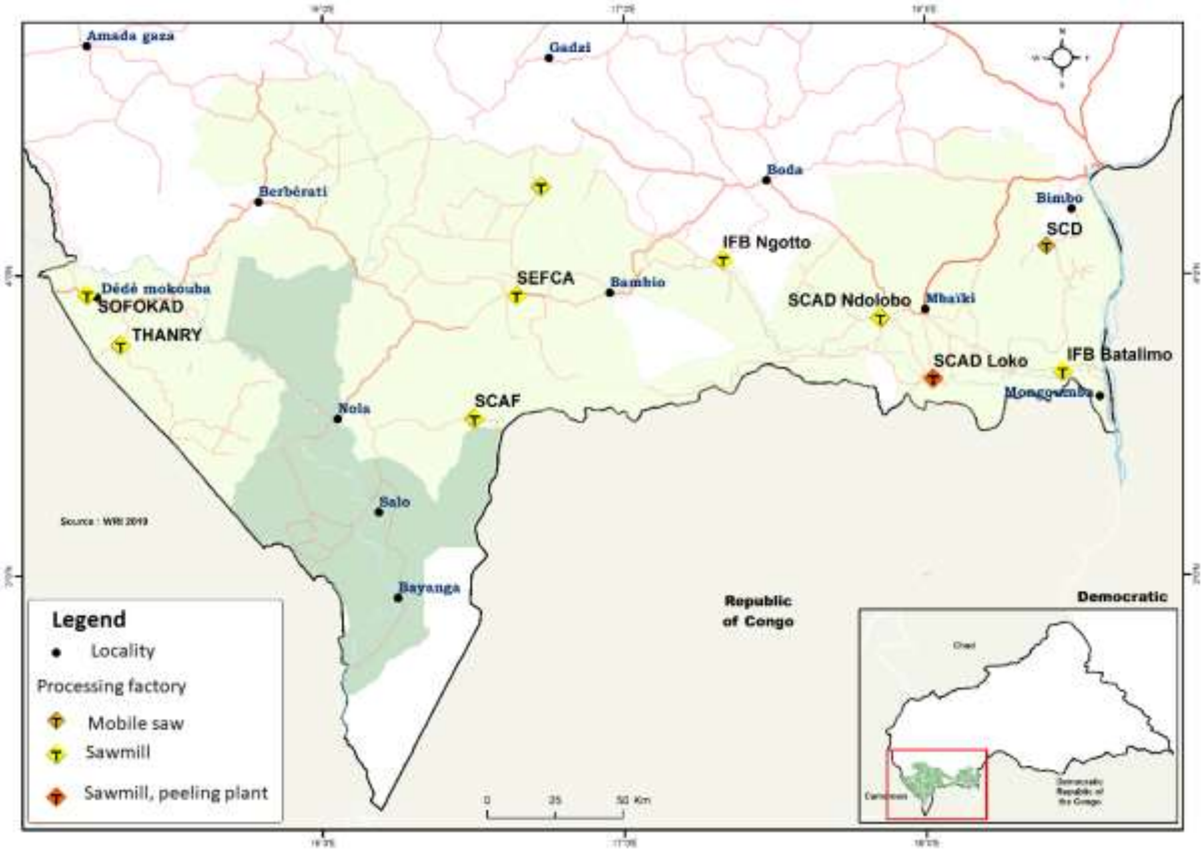

Figure 13: Location of wood processing plants/units in Central African Republic

4.2.6. Benin

Benin in west Africa, based on the productivity assumptions for natural formations and agricultural terroirs, an assessment of forest productivity was established.

Table 9: Productivity assumptions in Benin

Stratum	Productivity assumptions[1]	Annual wood production per stratum	
	M³/ha/year	M³/year	T/year
Dense forest	2	137 304	96 113
Forest gallery	2	576 846	403 792
Clear forest/Wooded savannah	1,2	1 806 884	1 264 819
Savannah with trees and shrubs	0 ,8	4 648 513	3 253 959
Mosaic of crops and fallow land	0,6	1 671 236	1 169 865
Mosaic of crops and fallow under palm trees	0,4	197 505	138 254
TOTAL		9 038 289	6 326 802

Productivity assumptions[1] : Source: IFN 2007, Hubert Forster estimates.

Annual wood production was therefore estimated at 9,038,289 m^3. This production, as can be seen, does not take into account that of plantations, which cover very heterogeneous realities such as timber plantations, orchards, cashew tree plantations and fuelwood plantations.

The mission considered in its report that 90% of the production (excluding plantations) is potentially usable as wood energy. So to speak, from the above estimated value, the annual production of wood energy can be estimated at around 5,700,000 tonnes (8,134,460 m^3) in 2007. This value is not very far from that of the EIS 2015 report of the Directorate General for Energy. Indeed, in this report, it is estimated that the total quantity of fuelwood taken from the forest amounts to 7,125,996.4 tonnes. This productivity is determined on the basis of values of 5 tons/ha for dense forests, 1.2 tons/ha for clear forests and wooded savannas and 0.6 tons/ha for wooded savannas, weighted with the percentage represented by each type of forest formation[8].

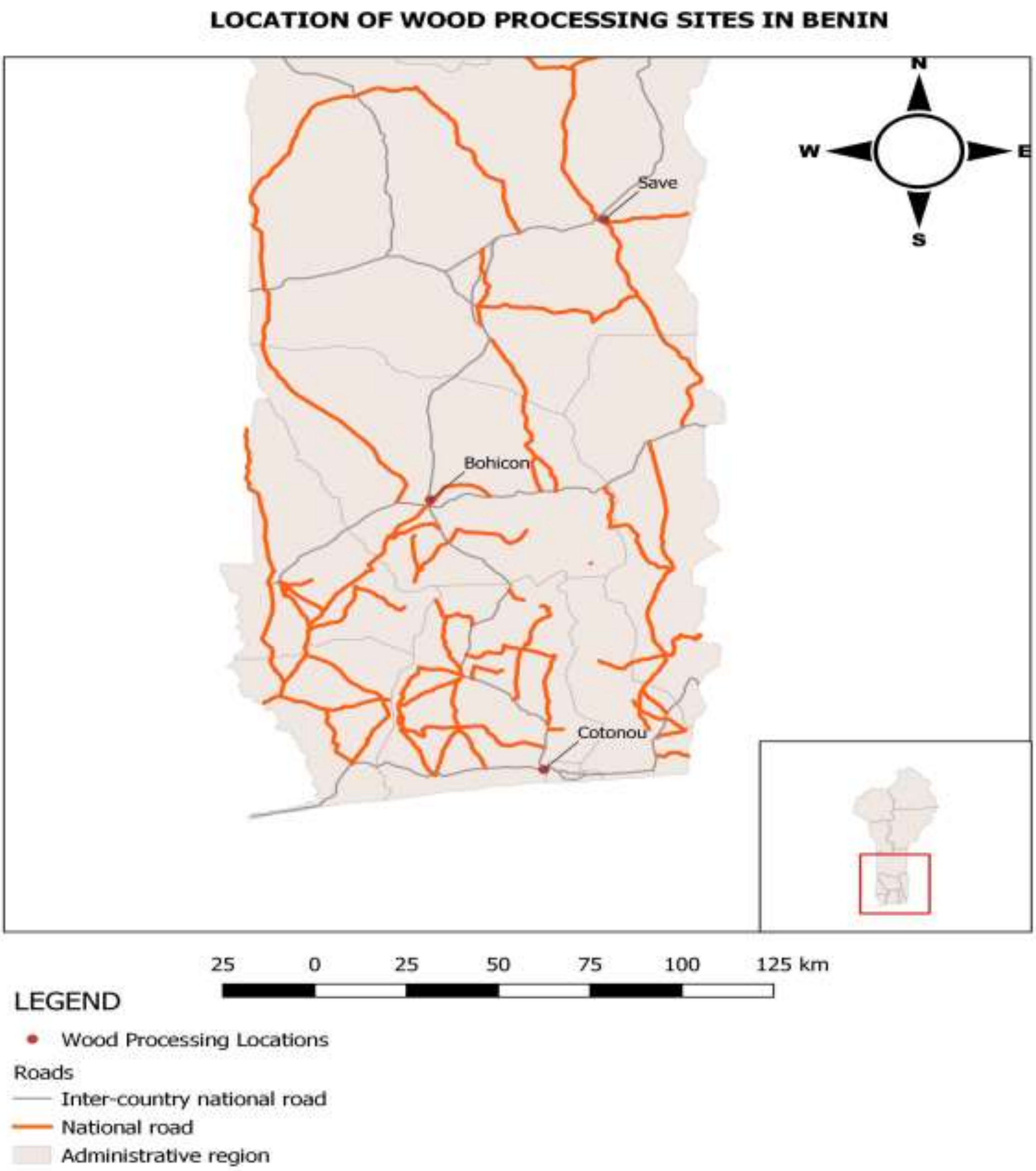

Figure 14: Wood processing sites in Benin

[8] **Invalid source specified.**

Table 10: Wood processing locations in Benin

Place	Purpose	X_Coord	Y_Coord
Save	Defforestation	2.502152	8.034764
Cotonou	Sawmills and wood transport hub	2.353842	6.378731
Bohicon	Mahukpenou Sawmill Location	2.07437	7.19064

4.2.7. Case of Cote d'Ivoire

4.2.7.1. Estimates of various forest biomass residues

The average area for the last three years is 3000 ha. Thus, 105,000 ha have been planted in classified forest or in the rural domain in 18 years, i.e. an average of 5,640 ha per year, not counting the year 2011. This does not include private reforestation, school projects or SODEFOR reforestation. The reforested species are essentially Teak, Samba, Gmelina, Cedrela, *Acacia mangium, Frake,* Framiré, Cheese.... The proportion of Teak is higher in rural areas than in classified forests (BNETD, 31 July 2015).

The main sources of forest biomass residues for energy and lumber and service remain to be:

- Biomass production sites.
- Biomass processing sites.
- Distribution and consumption sites for products from production and processing.

Table 11: Sources of forest biomass residues related to the "firewood" sector

Categories in the value chain	**Type of residue**	**Location**	**Actors**	**Current use**
Primary mining (cutting and cutting wood)	Houppiers	Forêts I'm going to have Plantations	Households Individual operators	*Not known*
	Branches			*Not known*
	Strains			*Not known*
Distribution	Twigs	Points of sale	Traders (retailers, wholesalers)	*Not known*
Consumption	Coal	Private house Agri-food production site	Households Uprofessional sagers	*Not known*

Table 12: Sources of forest biomass residues related to the "lumber and service" team

Categories in the value chain	**Type of residue**	**Location**	**Actors**	**Current use**
Primary mining (cutting and cutting wood)	Houppiers	Forêts I'm going to have Plantations	Loggers Wood-operators	*Not known*
	Branches			*Not known*
	Strains			*Not known*
Secondary mining (wood processing)	Ecorces	Scieries Menuiseries	Wood processing industry Artisans	Used as fuel in households and agri-food industries

Categories in the value chain	Type of residue	Location	Actors	Current use
	Wooden shavings	Scieries Menuiseries	Wood processing industries Artisans	Used as fuel in households and agri-food industries
	Sawdust	Scieries	Wood processing industries	Partially used as fuel in households
	Coal dust	Carbonization sites	Coal	*Not known*
Consumption	Coal dust	s Coal point of sale Houses	Traders Households Craftsmen	*Not known*
	Recovery wood (palette, wood preventing construction)	Sites Stores	Building and construction professionals traders	*Not known*

The availability of bioenergy residues was assessed by BEFS RA at a country level for Ivory Coast in 2016. To estimate the availability of logging for bioenergy purposes, data on industrial timber production was provided by the Ministry of Water and Forestry of Côte d'Ivoire. For the production of wood as fuel, the source of information was FAOSTATS statistics. The results obtained in 2016 are recorded(FAO, Bioenergy and Food Security / Rapid Assessment, February 2016)in the table below.

Table 13: Availability of logging tailings for bioenergy purposes in Cote d'Ivoire

Residuals available		
Unit	**m³/an**	**t/an**
Conifers	-	-
Non-conifers	698 543,7	405 155,3
Total	**698 543,7**	**405 155,3**

Source: (BEFSRA Analysis - Wood Tool as Fuel)

For the estimate of the availability of wood processing for bioenergy purposes, production data were provided by the Ministry of Water and Forestry of Côte d'Ivoire. (FAO, Bioenergy and Food Security / Rapid Assessment, February 2016)The results obtained in 2016 are presented in the table below.

Table 14: Availability of wood processing residues for bioenergy purposes in Cote d'Ivoire

Types of tailings	**m³/an**	**t/an**
Sawdust	60 192	30 096
Plates and fleas	209 059	104 529
Total	**269 251**	**134 625**

Source: (FAO, Bioenergy and Food Security / Rapid Assessment, February 2016)

Results on the availability of timber residues from logging and wood processing activities show that there is high potential in the country.

It should be noted that logging residues are located in tree felling sites and therefore the collection and cost of transportation should be taken into account when analyzing the feasibility of using these residues for bioenergy.
On the other hand, wood processing residues are generated in sawmills and are potentially already available for bioenergy purposes.

Table 15: Evolution of the wood processing residues for bioenergy purposes in Cote d'Ivoire from 2004 to 2010

Characteristics	Volumes in m³						
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total volume entered the factory	1 920 107	1 755 971	1 603 817	1 642 160	1 656 758	1 037 631	1 453 561
Total products from the first process	814 829	752 485	703 919	752 950	740 211	478 352	490 462
Availability of forest biomass residues (m³)	1 105 278	1 003 486	899 898	889 210	916 547	559 279	963 099

Source : *(MINEF, 2010)*

Apart from forest residues, there is also the potential for residues from the processing of NLFPs such as oil palm, cashew, cocoa and rubber that can be used for energy purposes.

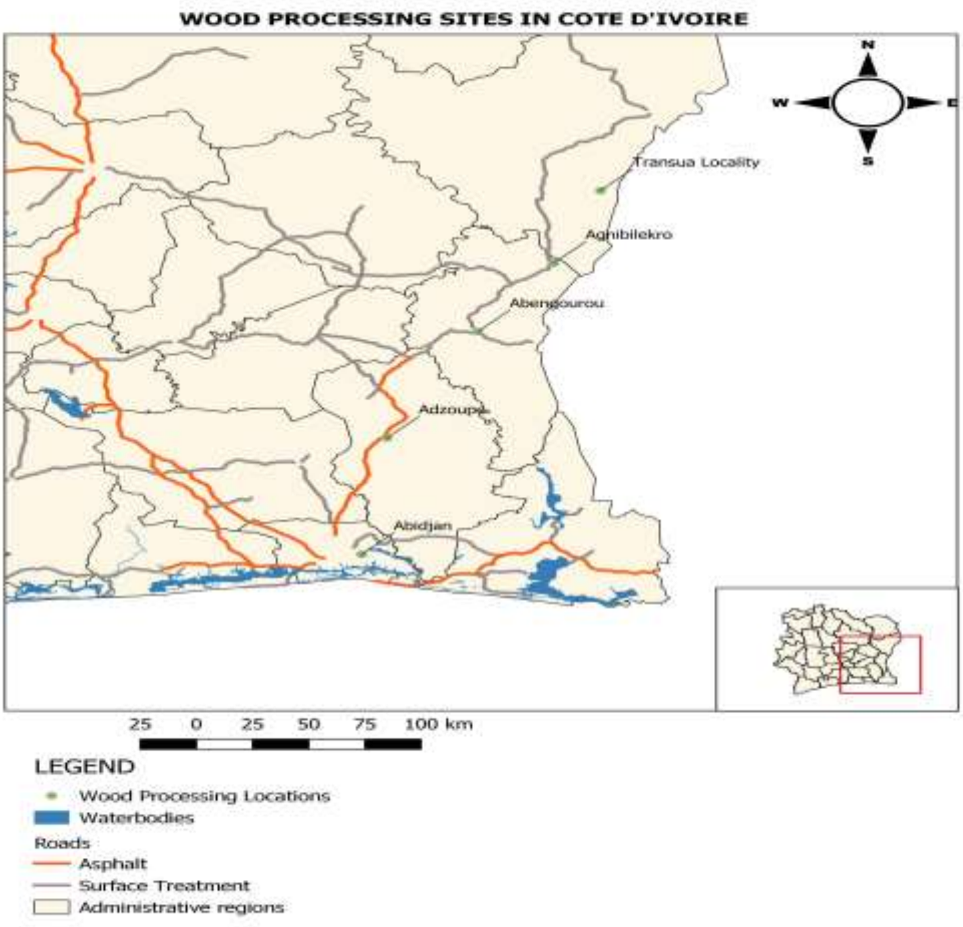

Figure 15: Wood processing sites in Cote d'Ivoire

Table 16: Location of wood processing sites in Cote d'Ivoire

Place	Purpose	X_Coord	Y_Coord
Adzoupe	Nouvelle Scierie D'Adzopé Hardwood Sawmill	-3.859927	6.087597
Abengourou	Nsefi SARL Tropical Hardwood Sawmill	-3.495319	6.723679
Abidjan	Dingshang Developpement Tropical Hardwood Sawmill	-3.960887	5.392102
Agnibilekro	SITBAI Wood Processing Company	-3.190732	7.133497
Transua Locality	SMCI Company	-3.003374	7.566822

4.2.8. Case of Senegal

In Senegal, as in other Sahelian countries, traditional fuels (firewood and charcoal) are the main sources of household energy. Indeed, Senegal depends on more than 70% of forest resources to meet its cooking energy needs (Frank Richter, Marion and Abdoul A SOW, August 2014). This logging is one of the causes of the degradation of forest resources, especially when combined with agricultural clearing and bush fires. In 2013, with the support of PROGEDE 2, a national survey was conducted on domestic fuel consumption and household practices. The results of the 2013 household survey met with the consensus of all national stakeholders. They reveal that the quantities of cooking fuels used in Senegal are :

- 1,735,219 tonnes for firewood ;
- 482,248 tonnes for charcoal ;
- 108,001 tonnes for butane gas.

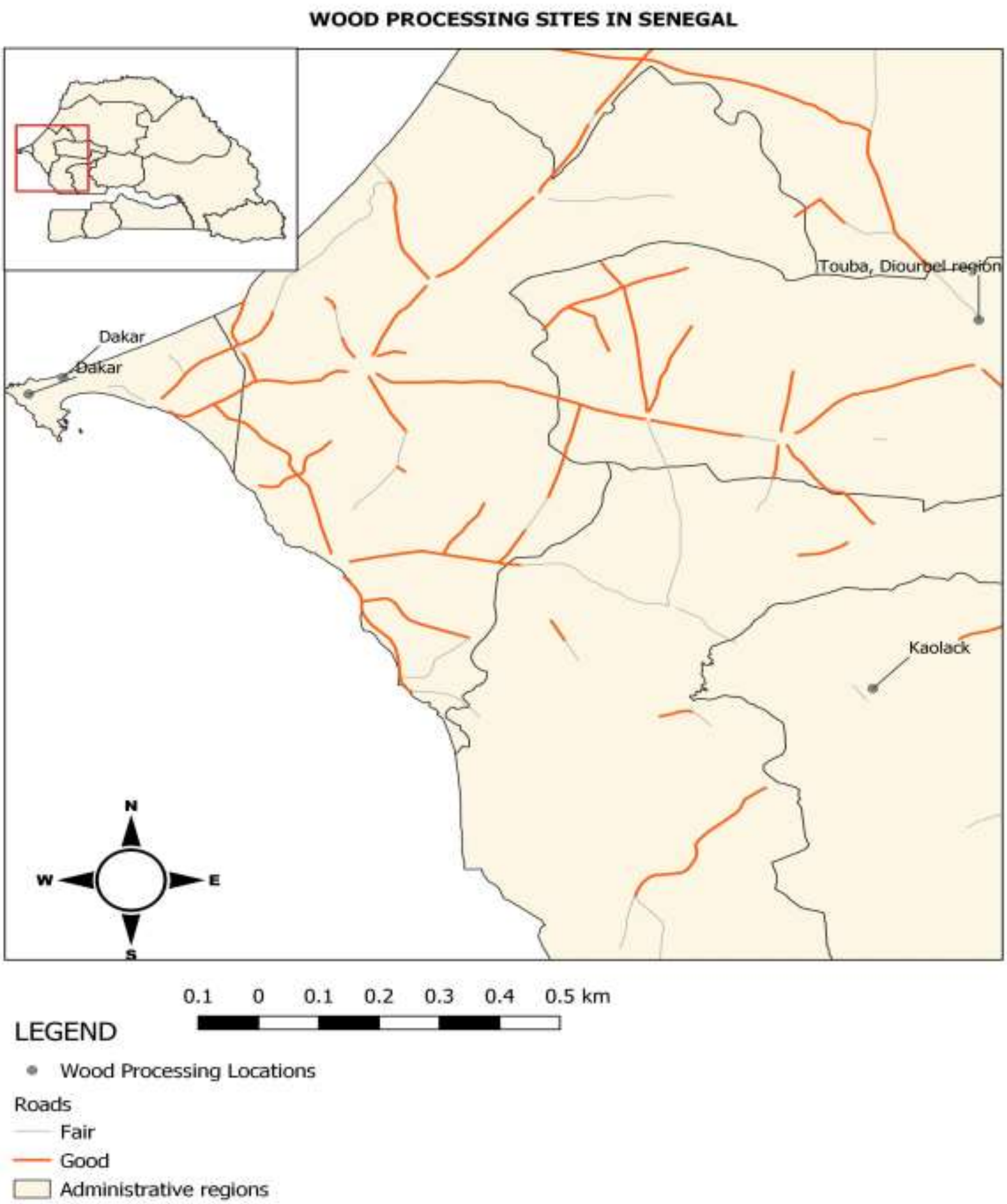

Figure 16: Wood processing sites in Senegal

Table 17: Wood processing locations in Senegal

Place	Purpose	X_Coord	Y_Coord
Dakar	Pikine Sawmilling Compound	-17.484551	14.737246
Kaolack	Lagal Sawmillingl Compound	-16.083911	14.177963

Place	Purpose	X_Coord	Y_Coord
Dakar	Victoria Star Darkar- Logger, timber exporter	-17.427827	14.768601
Touba, Diourbel region	Wood-mizer Branch (wood product processing)	-15.908333	14.877921

4.2.9. Togo

The ECO Consult firm has estimated, in 2017, the total consumption of wood energy in Togo at 7.576 million cubic meters per year. This estimate is made using an elaborate simulation model and on the basis of total household consumption and that of professional consumers.

Table 18: Annual consumption of wood energy by socio-professional categories in Togo in 2017

Wording	Wooden Demand		
	(m³/year)	**(t/year)**	**(%)**
Urban and rural households			
Firewood	2 150 294	1 505 206	28,4
Charcoal[9]	4 074 923	2 852 450	53,8
Sub-total household consumption	**6 225 217**	**4 357 656**	**82,2**
Professional consumers			
Firewood	883 125	618 188	11,7
Charcoal6	468 580	328 010	6,2
Sub-total consumption of professionals	**1 351 705**	**946 198**	**17,8**
Total	**7 576 922**	**5 303 854**	**100,0**

Thus, in 2017, demand exceeds potential wood energy production in Togo and the theoretical deficit between supply and demand amounts to 4,296,216 m³/year, a factor of 2.3.

[9] In wood equivalent, calculated with a carbonisation efficiency of 10% and a wood density of 0.7 t/m³.

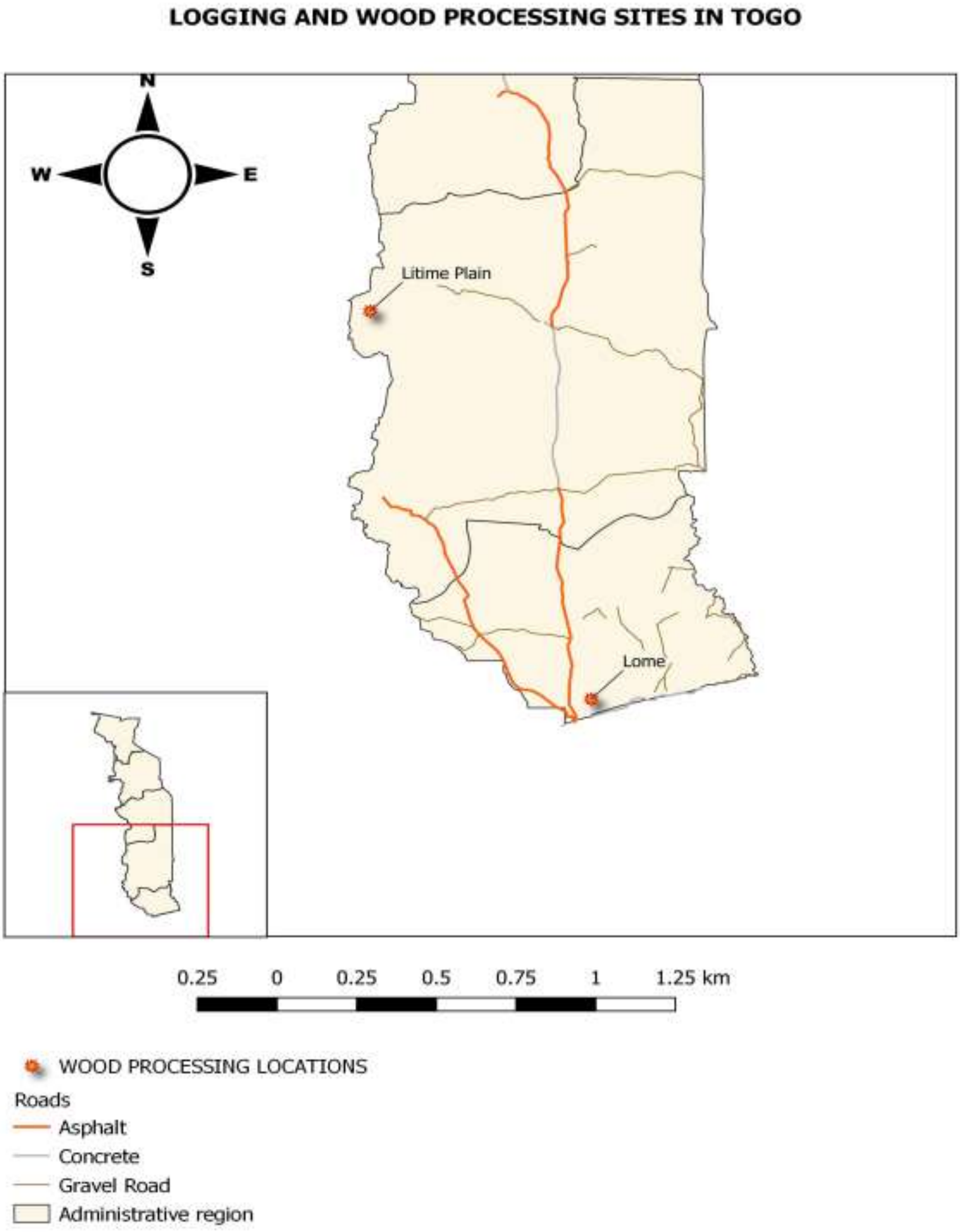

Figure 17: Wood processing sites in Togo

Table 19: Wood processing locations in Togo

Place	Purpose	X_Coord	Y_Coord
Lome	NKSIM GR SARL U -wood exporter, sawing services	1.283032	6.198871
Litime Plain	Artisanal, Logging, Illegal Logging	0.589335	7.556391

4.2.10. Burundi

The main sources of forest biomass production are: the Gakara-Gahuni State Forest, the co-managed afforestation of Magara in Ngozi, the co-managed afforestation of Ntamba in Muyinga, the VYANDA-BURI State Forest, the Rugazi State Forest [3] and private afforestation. Geographic location and key variables in forest resource assessment.

The total forest (Gakara-Gahuni) covers about 2000 hectares, of which about 1150 hectares are jointly managed. The tree species are eucalyptus trees. The volume of usable wood in the co-managed area is estimated at an average of 670,197 m^3 (six hundred and seventy thousand one hundred and ninety-seven.) In terms of management, the Gakara-Gahuni block is co-managed between the State represented by the Forestry Department and groups of people known as the Participative Management Group (GGP), i.e.:

1. Mashambaramba
2. Dukingiribidukikije
3. Rwanyubukene
4. Garukirigiti

Co-managed afforestation in Magara de Ngozi where the tree species are eucalyptus, the area is 60.45 hectares. The total volume is 2891 m^3,

Co-managed afforestation in Ntamba de Muyinga with eucalyptus as tree species. Area of 30 hectares and unknown volume.

Rugazi State Forest with the following tree species: deciduous and coniferous including pine, callitris, eucalyptus, grevillea, etc. The area is 2175 hectares. The usable volume remains unknown.

Private afforestation: Private forest plantations are highly concentrated in the medium and high altitude regions (1200 and 2000 meters above sea level) and precisely in the provinces of Bururi, Bujumbura rural (nyabiraba), Muramvya (Bugarama and Ryarusera), Mwaro (Bisoro and Gisozi) and Gitega (Ryansoro and nyarusange), etc. The main variables in the assessment include tree species: several varied species. The area and volume remains unknown.

4.2 Conditions of availability (scattered or concentrated, accessible, good quality, quantity, legal restrictions)

Condition of availability have involved a study of sources of residues , accessibility, quality and quantity and any legal restrictions. To determine the total available wood processing residues, statistical data will be used on the quantity of roundwood used for sawn wood production, annual sawn wood production, the sawmill recovery rate, which is the ratio of sawn wood to roundwood (sawdust recovery rate and recovery rate of slabs and chips). The amount of wood processing residues available for bioenergy is calculated as follows:

Gathering of data on forest sources from individual countries, that is, roundwood and fuelwood production is in the process. The collected data will be analysed and where possible compared with official national and FAO sources. FAOSTAT, which is the database maintained by FAO, provides global figures on forest products. The figures are measured in cubic metres (m^3) or tonnes (t) on an annual basis. FAO latest data which will be used in this study is contained in the Forest Resource Assessment report was released in July 2020 edition. Data are presented in terms of area in hectares (ha) or multiples of hectares, while biomass is provided in tonnes. Different measures of forest are therefore used based on an appropriate unit of measurement. The inadequacy in countries data on residues generated at sawmill sites, have been made up by collecting information on primary wood processing from the ministries of forests, energy, etc., Since the data is likely not to be available for all countries, FOASTAT will be used.

Due to the different regions (Central Africa, East Africa and West Africa) and the associated variation in tree species and wood quality, a differentiation will be made on the types of forests and sawmills in the different study countries.

For instance, Central African mills process large, high quality logs to produce a wide range of specialized products while East and West African mills use smaller, lower quality logs to produce commodity type products. To support the objective of quantifying residues in the study countries, specific factors such as residue utilization and actual raw material availability by country will be analysed to give an overview of all potentially available plant sites and their close distances in kilometres, as they could also serve as bioenergy plant sites. Estimate of mill capacity in relation to roundwood production in order to estimate the supply of residues will be carried out as well as calculations of distances close to transportation costs. Lastly, identification of mills based on cost rankings highlighting existing and new bioenergy facilities that may be better located along the cost curve.

4.3. Considerations on sustainability of this resource

Increased bioenergy residue usage is most likely to occur and will therefore call for increased whole-tree harvest, subject to applicable country's regulatory forest practice rules. To ameliorate such situation, there is need for growing a purpose-grown bioenergy crop on forest land, and or looking for more bioenergy feedstock from existing agriculture and forest landscapes. These crops could include low-value trees such as the invasive Prosopis juliflora or perennial energy crops, either intercropped in or grown in a mosaic with traditional plantations.[10] The other option is the use of residues from agricultural crops such as cashewnuts, shea butter, sugarcane bagasse and palm oil.

Other sustainability measures suggested by a recent UNEP study include :[11]

- Exploit non-wood feed stocks as substitutes for wood biomass. Encourage the use of agro-industrial Wastes through processes that transform them into pellets and briquettes as alternatives to woodfuel and charcoal and hence reduce dependence on woodfuel
- Encourage the production and use of micro-gasifier stoves that have recently been introduced through greater research and development for scaling up. This stove holds great potential as it uses agro-industrial wastes directly, thus reducing dependence on woodfuel.
- Promote the greater application of biogas technology in an integrated approach where possible, using waste streams to further reduce pressure on natural forests and for cleaner and healthier sustainable energy for cooking, heating and power generation

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[10] *Nettles, J., Birks, P., Sucre, E. et al. Sustainable Production of Bioenergy Feedstock from the Industrial Forest: Potential and Challenges of Operational Scale Implementation. Curr Sustainable Renewable Energy Rep 2, 121–127 (2015). https://doi.org/10.1007*

[11] *UNEP (2019), "Review of Woodfuel Biomass Production and Utilization in Africa: A Desk Study" United Nations Environment Programme*

4.4. Prospective available sources

4.4.1. Forest plantations

large energy plantations would be required to supply bio-energy conversion facilities, hence the need for proper planning to avoid land use conflicts. Being low energy-density fuel, to avoid high transport costs would require that plantations be grown as close to the conversion facilities as possible. This is likely to displace traditional farmers and provoke conflict. Government measures to protect the small farmers near the conversion facilities and to regulate other land-use becomes very essential, considering beneficial effects such as bioenergy conversion plants potential to generate rural employment, generate revenue stream for other agricultural products, and reduce greenhouse gas. An option that is becoming increasingly popular, is agroforestry coupled with integrated farming, which makes bioenergy programmes have the potential to improve food production by making available both energy crops and incomes. The agricultural production of biomass can be increased by substituting monocultural crops, planting forage crops and fast growing leguminous trees which enhance the soil, according to an agroforestry approach and incorporating land conservation systems such as windbreaks and shelter-belts. There is also potential to increase the use of crop residues, provided this is consistent with maintaining organic matter levels and controlling erosion.[12]

4.4.1.1. Legal frame

Renewable energy first became an official priority for international development agencies at the UN Conference on New and Renewable Sources of Energy held in Nairobi in 1981 which called for research , planning, investment and dissemination of renewable energy technologies.[13] Since then two kinds of initiatives have emerged:

- legal or regulatory developments to encourage private investment in renewable energy sources and applications, and
- financial assistance to public or private investors from national, bilateral or multilateral sources for capital intensive projects.

At the international level, the promotion of bioenergy and biofuels as a viable renewable energy alternative to fossil fuels has centered around sustainable development and the environment; climate change and its mitigation and international trade.

To promote sustainable bioenergy industries the above issues coupled with legal issues surrounding land, forest and water resource management must be carefully assessed to determine how bioenergy production may contribute to the development of rural communities and environmental sustainability. Governments in developing national bioenergy legislation, need to enforce regulations governing agricultural and forestry use, habitat and biodiversity protection, water, soil and air quality management, and waste disposal. In addition, regulations governing environmental impact assessments are essential components of an effective natural resource management legal framework and sustainable development strategy for bioenergy.[14]

In conclusion, the legal frame for bioenergy conversion will be guided by the countries policies, legislation and regulatory framework that guide natural resource management including forestry and wildlife, agriculture and waste management.

[12] *FAO 2007 : Forests and energy in developing countries*

[13]

[14] *FAO 2007: THE LEGAL FRAMEWORK FOR BIOENERGY: Charlotta Jull et al*

4.4.1.2. Most suitable species for plantation

4.4.2.Non-timber forestry products with an energy potential

4.3 Options in Country's most promising chain links and hotspots

The potential for use of forest biomass residue across the three regions and in countries varies. Central African countries has the great potential since most countries have large mills able to produce high quality logs for a wide range of specialized products while East and West African mills use smaller, lower quality logs to produce commodity type products. Central Africa is the region with the most abundant forest biomass with vast areas of tropical forest. The combination of large areas and very dense biomass forest is due to high rainfall and excellent growing conditions for tropical tree species. Below is a summary of the most promising chain links and hotspots in the three regions.

4.4.3. Central Africa countries

- Cameroon - Most of the production forests are concentrated in Eastern Cameroon with a high concentration in Boumba and Ngoko and Haut Nyong, followed by the southern region and then the central region. Most forest biomass residues come from forest concessions, generating about 1, 245,791.32M^3 according to **2013 data.**
- Congo – The country's forest estate is composed of two large areas, north and south, with north having the largest share making it a forest biomass residue hotspot. In 2018, logging and industrial companies produced 1,831,746.52 m^3, or a potential 842,603.40 of residues. Six potential sites for bioenergy plants in the localities of Likoula, Sangha, Lekoumou, Niari North, Niari South and Kouilou have been identified.
- Democratic Republic of Congo - The Tshopo, Equateur and Maï-Nombe provinces alone contain 71% of the forest concession contracts granted by the Congolese state to companies, with most production forests located in the northern and western regions of the countries.
- Gabon - Production forests are concentrated, notably the localities of Mtzic (Woleu Ntem), Makokou and in the vicinity of Ovan (Ogoue Ivindo), Ndjole (Moyen Ogoue), Fougamou (Ngounie), Kango (Estuary) and Lastoursville (Ogoue Lolo). The Estuary Province has the highest potential with 76 wood processing units with sawing and veneer as the main transformation.
- Central African Republic – Most of the logging titles (Operating and Development Permit (PEA) are concentrated in the southern part of the country. Priority hotspots are located near UTB Thanry in the Mambéré-kadei prefecture, SEFCA in the Sangha Mbaéré prefecture, and SCAD Ndolobo in the Lobaye prefecture.
- Case of Equatorial Guinea – the estimated forest potential is 1,972,044 hectares. The production forests do not have adequate potential to generate enough forest biomass.
- Chad – Most of the forest is located in the south of the country, however, the country has very low forestry potential.

4.4.4. West Africa

- Mali - Wood production and processing is very low and not very concentrated in one area and hence wood biomass residue potential is very low. The Shea butter value chain is the most promising. Processing of nuts into shea butter has a high potential and MaliShi plant may be one of the places to consider since it has potential of producing 20,000 tonnes of shea nut shells and 15,000 tonnes of oilcake.
- Benin – Production forests cover 3% of the forest estate and may not generate adequate biomass but there is a huge potential from processing of cashew and shea nut butter since Benin is a major exporter of the two

products. The most favourable area for cashew nut production is the central region which has 87 of the country's cashew nuts orchard followed by the north eastern region.

- Senegal – the forest value chain is dominated by the woody energy value chain that is largely comprised of charcoal and firewood. Timber exploitation has been stopped in some of the forest areas such as Kolda, Sédhiou and Ziguinchor regions as from 2018. Hence this value chain does not seem to have adequate biomass residue for consideration in bioenergy.
- Cote d'vore – most of the forests are concentrated in central and southern parts of the country. A total of 967,795M^3 of forest biomass residue is available per year distributed as 598,544M^3 of logging residues and 269,257M^3 of wood treatment residues.
- Burkina Faso – This is not a timber producing country and imports 93% of the timber. Therefore potentially valuable forest residues in the wood value chain remain very low. Cashew nut and shea butter value chains have good biomass residue potential, with Cascades and South-West regions covering 70% of the cashew nut production in the country. Processing of 50% of an annual production of 200,000 tonnes of cashew nuts would produce 56,000 tonnes of hulls for valorisation. The Centre West region has the highest potential for shea butter. Processing of 79,500 tonnes of processed almonds from shea butter would generate about 28,000 tonnes of waste cake for bioenergy.
- Togo – this is also not a timber producing country and therefore like Burkina Faso, cashew nut and shea butter would be the most appropriate value chains for biomass residues. Processing of cashew nut can generate 4,000 tonnes annually of recoverable hulls while processing of shea butter by NIOTO company, one of the largest in the country has a potential of generating around 10,000 tonnes of waste cake annually.

4.4.5. Eastern Africa

- Burundi – Burundi is not a timber producing country but the limited resources in some of the industrial forest areas such as the State forest of Gakara-Gahuni with an estimated average production of 670,197M^3 supplemented by other sources of biomass residue (e.g from agroforestry) would be a priority since compared to West Africa, there are no agricultural crops that produce waste in large quantities.
- Djibouti – With no industrial forests, Prosopis remains the only potential biomass residue for bioenergy. Four areas with dense Prosopis cover in Djibouti: Douda, Hanlè, As Eyla and Tadjoura are key hotspots for Djibouti.

4.4 Developing a prioritization methodology (same for all countries, allowing for regional variations)

Here we list the criteria and indicators that will be considered in the feasibility and impact assessments later on (Outputs 3 and 4 → selection of pilot project shall be done in Output 5)

4.5.1. Tools for prioritization

The purpose of this section is to identify the criteria and indicators that will be considered to assess the feasibility and impacts of all aspects of the project.

4.5.2. Bioenergy and Food Security (BEFS) analytical framework and tools

The BEFS rapid assessment is an approach developed by FAO that helps countries design and implement sustainable bioenergy strategies. It consists of a set of easily applicable methods and user-friendly tools that allow countries to get a first indication of their sustainable bioenergy potential and the associated opportunities, risks and trade-offs.

This approach will also be applied in this study to analyze the feasibility of bioenergy projects and the prioritisation methodology to select the pilot project.

The BEFS Detailed Analysis covers four main areas: diagnostic analysis, natural resource analysis, techno-economic and environmental analysis, and socio-economic analysis.

- The Diagnostic Analysis examines trends in national energy markets.
- In the case of this study, the assessment of natural resources will include the forests of each country considered in the study.
- Techno-economic and environmental analyses will be carried out to generate information on the costs of bioenergy production and the impact that the various bioenergy production chains have on GHG emissions.
    - Bioenergy production costs are based on raw materials, type of by-products and other production technologies. In the analysis, scenarios are identified to determine the type and amount of fuel, feedstock, conversion technologies, and who should supply the feedstock (plantations, forests). The choice of technology is based on the country's technological capacity, human skills and access to the inputs needed for bioenergy production.
    - The greenhouse gas (GHG) analysis defines the GHG balance for the production of bi-products based on the scenarios identified in the production cost analysis. The analysis should identify the bioenergy production pathways that can offer the greatest reductions in greenhouse gas emissions.

- The socio-economic analysis will focus on economy-wide impacts and includes a household vulnerability analysis.
    - Economy-wide impacts: This will help define the impacts of bioenergy sector development on the economy as a whole, including its impacts on employment, growth and poverty. The analysis will build on the results of the techno-economic analysis, integrating them into a broad national model.
    - Household Vulnerability and Security Analysis: This analysis is based on data from the Bioenergy Value Chain Survey and can help policy makers understand which segments of the population may be vulnerable to price changes.

4.5.3. Multi-criteria analysis

Multi-criteria analysis provides a framework to analyze the decision-making context and structuring the decision-making process. Multi-criteria methods make it possible to use criteria of various kinds: financial, economic, technical, political, etc. In the context of this study, multi-criteria analysis will make it possible to target the most promising new projects, in relation to the intended purpose (according to set criteria).

The advent of new projects gives rise to two main streams of monetary assessment: financial analysis and economic analysis. The purpose of financial analysis is to ensure the return on capital invested by companies, while the purpose of economic analysis is to help prepare and select projects that make the greatest contribution to economic development.

The tools that are frequently found in economic or financial analyses presented in the literature and that could be used in this study:

- Benefit-cost analysis, which will compare the benefits and costs of an activity or investment so as to undertake only those activities where the benefits exceed the costs;
- Cost-effectiveness analysis will allow the value of benefits to be estimated on bases other than monetary value.

4.5 Main criteria for prioritization

4.6.1. Availability of natural resources

This section identifies the most important types of biomass, residues and waste streams available for bioenergy production in the countries under consideration and provides an overview and introduction to these different sources of raw matter for biomass energy projects.

Criteria such as availability, quantity and type of biomass will determine the types of technologies appropriate for the specific biomass project. This approach reflects that a number of supply chains will dominate for each project type depending on the availability of biomass and the choice of technology.

The objective is to characterize the relevant raw material, classify the types of biomass, and the potential resource constraints and how to identify them.

4.6.1.1. Availability of exploitable waste forest biomass

Establishing a secure supply of biomass is a prerequisite for the success of a biomass project. The guarantee of a stable year-round supply of biomass of sufficient quality depends both on the availability of biomass and the efficiency and stability of the supply chain. Biomass availability and the biomass supply chain are criteria that will be taken into account when analyzing the feasibility of projects.

Attention will also be paid to security of supply, including supplier risks, seasonal variations and the possible need for additional purchases of other types of biomass residues or wood pellets in the event of a supply shortage.

4.6.1.2. Land availability

The availability of biomass for energy production is affected by different factors at various spatial scales. On a global scale, it depends on land availability and productivity. The analysis of the feasibility of projects will therefore place particular emphasis on the availability of land to produce/cultivate the necessary biomass.

Access to land will also be a factor to be considered for each of the case studies, as in some cases the actors who have access to the land where the biomass is produced generally have ownership or the right to manage and enjoy the biomass waste. On the other hand, the biomass conversion facility will have to be located as close as possible to the biomass deposit, and therefore the accessibility of the property for a third party actor has to be assessed.

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