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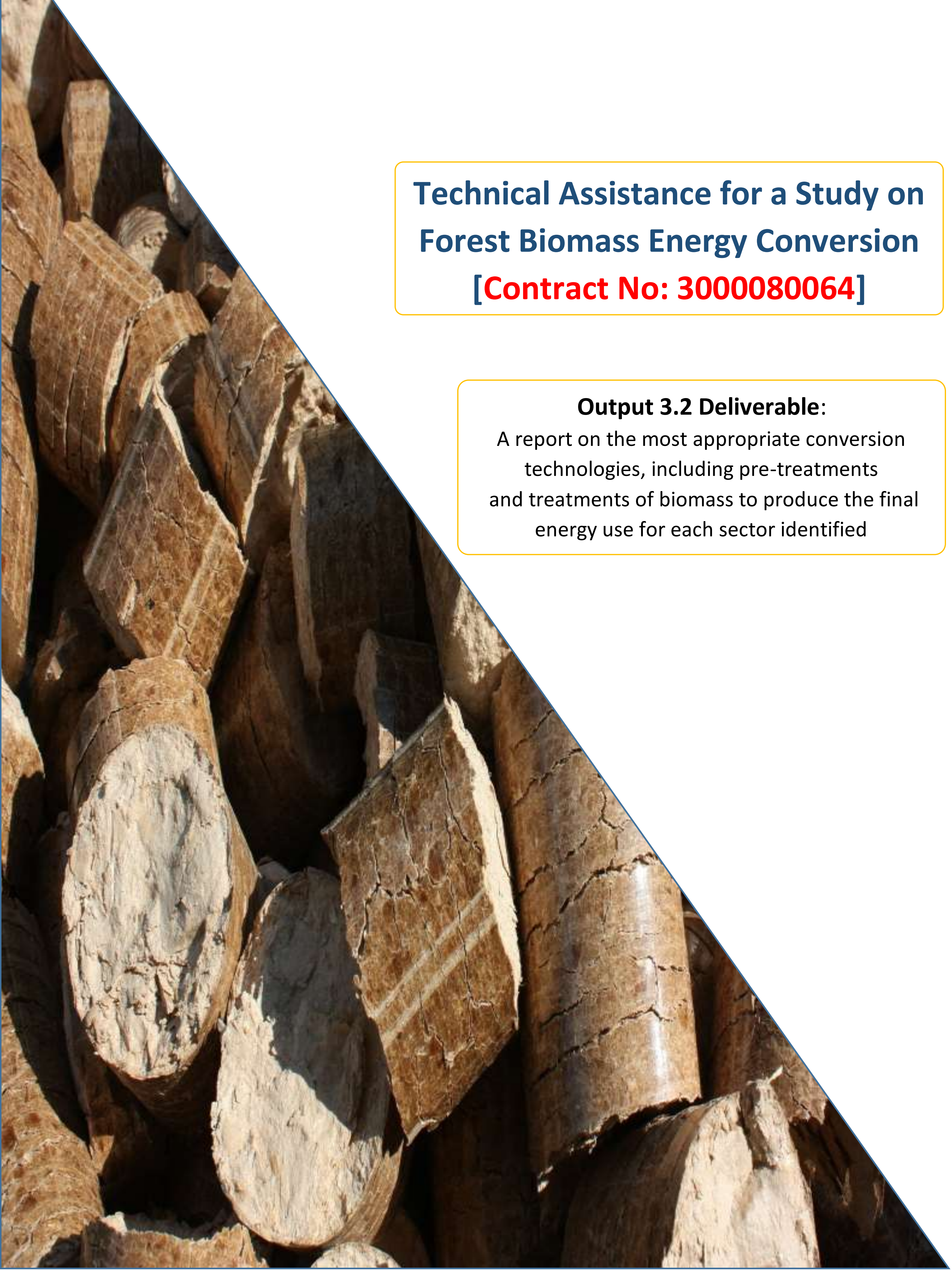

Technical Assistance for a Study on Forest Biomass Energy Conversion [Contract No: 3000080064]

Output 3.2 Deliverable:

A report on the most appropriate conversion technologies, including pre-treatments and treatments of biomass to produce the final energy use for each sector identified

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List of Abbreviations/Acronyms

Abbreviation	Title
AD	Anaerobic Digestion
AEEP	Africa-EU Energy Partnership
AFREC	*Africa Energy Commission*
ALUCAM	Aluminium of Cameroon Company
APNFP	*Association of Natural Forest Owners and Plantations Affery*
CCI	Congo Carbo Industry
CCIC	Cameroon Chamber of Commerce and Industries
CH4	Methane
CHP	Combined Heat and Power

CIA	*Central Intelligence Agency*
CIAB	*Comité Interprofessionnel de l'Anacarde du Burkina Faso*
CML	
CNI	*Chantier Naval et Industriel du Cameroun* (
CNSL	*Cashew Nut Shell Liquid*
CO2	Carbon (IV) Oxide
CO3	Carbon Monoxide
COMIREP	*Comité de Pilotage de la Réforme des Entreprises Publiques*
DEFRA	Department for Environment, Food and Rural Affairs
DRC	Democratic Republic of Congo
EUEI	European Union Energy Initative
FCFA	*Communauté Financière Africaine Franc*
FONABES	*Forêts Naturelles et. Approvisionnement durable en Bois-Energie des villes du. Sahel*
GDP	Gross Domestic Product
GIA	Gender Impact Assessments
GICAM	*Groupement Interpatronal du Cammeroon*
GJ	*Gigajoules*
GMDR	Green Mad Retort
GWh	Gigawatts per hour
ICS	*Improved Cookstove*
IEA	International Energy Agency
INDC	Intentional Nationally Determined Contributions
KWh	Kilowatt per hour
LPG	Liquified Petroleum Gas
MAF	*Ministry of Agriculture and Food*
MEI	Ministry of Economy and Industry
MJ	*Megajoules*
MSW	Municipal Solid Waste
MW	Megawatts
NH4	*Ammonia*
PDSE	*Plan de Développement du Secteur de l'Electricité*
REDD	Reducing Emissions from forest Degradation and Deforestation
SDACD	*Bamako Domestic Fuel Supply Master Plan*
SE4All	Sustainable Energy for All

SME	Small and Medium Enterprises
SNE	*Société Nationale d'Electricité*
TWh	Terrawatts per hour
UNDP	United Nations Development Program
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
WFP	World Food Programme

1 Introduction

Countries with the most biomass residue were selected based on three main criteria i) political context ii) technical and, iii) commercial. The text box elaborates the three criteria.

The main activity under output 3.2 was to determine the most appropriate conversion technologies, including pre-treatments and treatments of biomass to produce the final energy use for each identified sector in selected countries based on the above criteria. Consideration was given to the most promising technologies amongst the most common biomass energy conversion technologies ensuring that gender, the environment, financial and other context specific factors are taken into account.

POLITICAL/CONTEXT
1. NDE/focal points are committed, engaged and available for discussion
2. There is support from the community and other stakeholders on the need to convert wood waste to an alternative energy
3. Government policies support off-grid/on-grid renewable energy development – has renewable energy feed-in tariff or net-metering policy, etc?
4. The project has contact persons in the country willing to provide any extra information

TECHNICAL
1. The country has adequate wood-waste from the forest or agro-forest trees
2. Wood waste is in accessible location
3 There is adequate data and information to carry out due diligence studies (environmental, economic, financial feasibility and gender studies)
4. Is there an alternative source or technology for electricity production in rural area? Indicate cost for electricity production from alternative technologies/sources
5. There is no alternative for charcoal production in rural area? Indicate cost for charcoal production for alternative technologies/sources

COMMERCIAL
1. There is demand for converted energy in the area or an off-taker willing to commit to buying the power/energy

Text Box 1: Criteria for selection of pilot study countries

Based on the above criteria the countries identified for pilot studies were:

Central Africa: Republic of Cameroon, Democratic Republic of Congo and Republic of Congo

West Africa: Burkina Faso, Republic of Côte d'Ivoire and Republic of Mali

East Africa: Republic of Burundi

The marking scheme that shows how selection of the above countries were carried out in each region has been appended.

Using web-based research, literature review and field mission, a classification of most used conversion technologies was outlined. This is a precursor to designing and developing pilot project proposal in the above selected countries as part of Output 4 and 5 of this study. Consideration will be given to the most utilised technologies globally and in Africa from anaerobic digestion-to-internal combustion engine, gasification-to-internal-combustion-engine and combustion-to-steam turbine among other technologies. The most promising ones will be prioritised and where applicable replicated in countries with similar conditions.

Consistent with the title, this report commences with classification and description of conversion technologies, followed by brief description of the sector identified in select countries and the socio-economic factors that makes bioenergy technology suitable in the selected countries.

2 Classification of conversion technologies

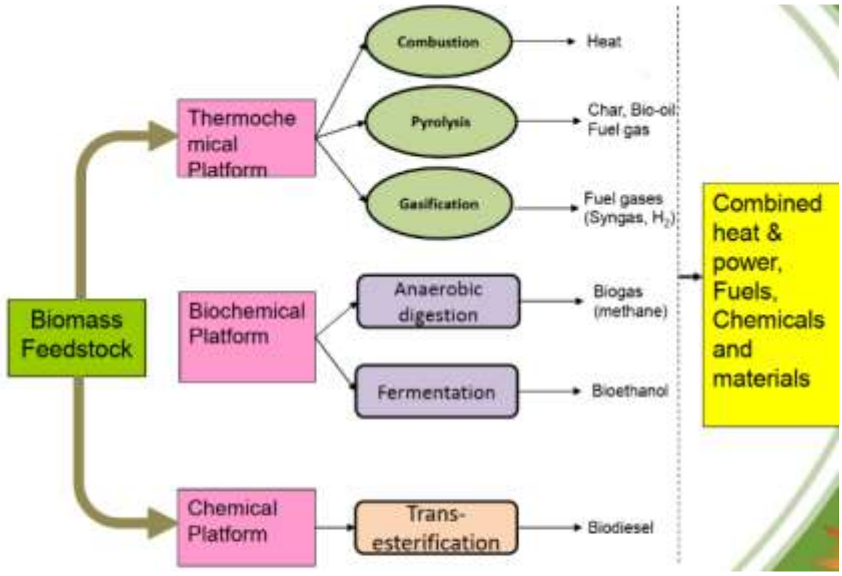


Figure 2: Forms of biomass energy conversion routes

Several bioenergy routes can be used to convert a range of raw biomass feedstock into a final energy product. The key driver for selecting a conversion process is normally the type of feedstock available, the desired energy products, scale and level of technology. A number of these technologies are already well developed and fully commercialised; while a range of other conversion, technologies are currently under development, which could potentially offer improved efficiencies, lower costs and improved environmental performance (IEA, 2009).

Different technologies exist or are being developed to produce electricity from biomass. Co-combustion (also called co-firing) in coal-based power plants is the most cost-effective use of biomass for power generation. Dedicated biomass combustion plants, including MSW combustion plants, are also in successful commercial operation, and many are industrial or district heating CHP facilities. For sludges, liquids and wet organic materials, anaerobic digestion is currently the best-suited option for producing electricity and/or heat from biomass, although its economic case relies heavily on the availability of low-cost feedstock. All these technologies are well established and commercially available (IEA, 2009).

In general, biomass-to-energy conversion technologies have to deal with a feedstock, which can be highly variable in mass and energy density, size, moisture content, and supplied intermittently. Therefore, modern industrial technologies are often hybrid fossil-fuel/biomass technologies, which use the fossil fuel for drying, preheating and maintaining fuel supply when the biomass supply is interrupted (Sharma, Meena, Sharma, & Goyal, 2014).

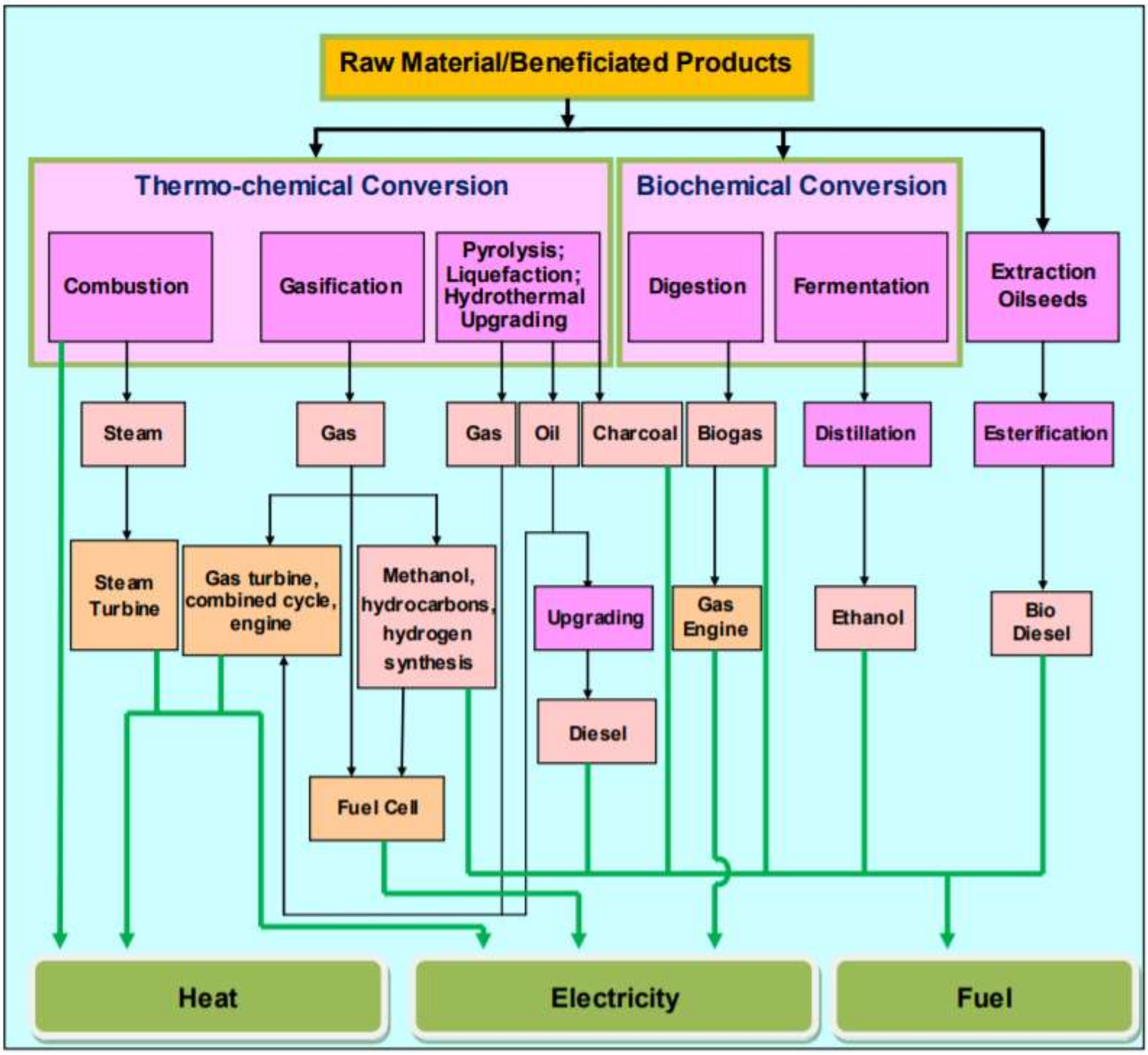


Figure 3: Methods of using biomass for energy

Source: (Sharma, Meena, Sharma, & Goyal, 2014)

2.1 Thermochemical process

2.1.1. Pyrolysis or carbonisation

Pyrolysis is the application of heat to a feedstock in the absence of oxygen to break down the long chain molecules into short chain molecules. Typically, the feedstock is biomass or waste, and the process is used to produce a syngas (a mixture of hydrogen, volatile organic compounds, and carbon monoxide). Varying the process conditions allows the production of fluids similar to diesel, and a variety of other products (Sharma, Meena, Sharma, & Goyal, 2014).

2.1.2. Combustion

The oldest and most basic form of biomass conversion is combustion. During combustion, biomass reacts with oxygen to release heat. Heat can either be used directly or harnessed to generate electricity. The level of sophistication of biomass combustion technologies ranges widely. In the simplest technologies, which have been used for centuries, the heat is used directly in stoves and brick ovens. Modern biomass combustion systems are used for domestic heating and in manufacturing and industrial operations to provide steam and hot water for processes (Cameron, Mozaffarian, & Falzon, 2014).

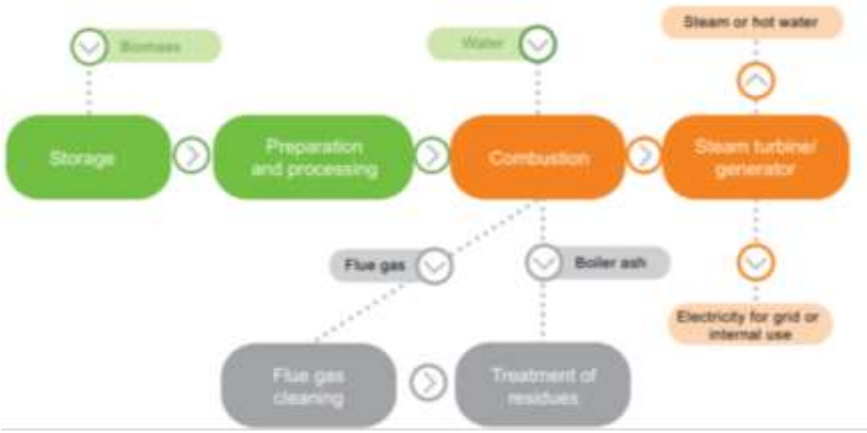


Figure 4: Flow diagram showing the process of electricity generation from biomass via combustion

Source: (Cameron, Mozaffarian, & Falzon, 2014)

Producing electricity from biomass combustion requires a two-step process. The biomass is first burned to generate steam, which is then used to drive a turbine that generates electricity. The conversion of steam to electricity using turbines is well established, with the first thermal power stations (operating primarily on fossil fuels) having been built in the late 19th century. The use of biomass as a feedstock to generate the steam in place of fossil fuel was introduced later, with the biomass either replacing a proportion of the fossil fuel (co-firing) or being used as a fuel in dedicated biomass power stations (Cameron, Mozaffarian, & Falzon, 2014).

2.1.3. Gasification

Gasification is the partial oxidation of an organic feedstock to produce syngas (a mixture of hydrogen, volatile short chain organic compounds, and carbon monoxide). Typically, the feedstock is biomass or organic waste, and varying the process conditions allows control over proportions of the compounds in the syngas. In this approach, the development of fixed carbon supplies from renewable carbon resources is to convert CO2 outside the biomass species to synthetic fuels and organic intermediates (Chyou, et al., 2020).

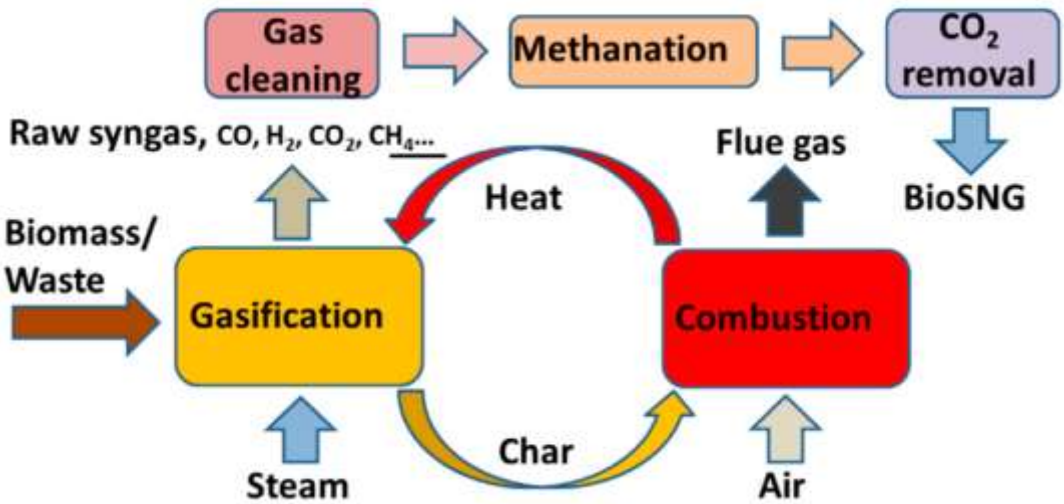


Figure 5: The gasification technology process

Source: (Chyou, et al., 2020)

2.1.4. Cogeneration

Cogeneration is a technology that provide more than one form of energy end-use – typically power and heat, but sometimes fuels as well – from a single source of energy. Multiple commercial and proven cost-efficient technologies for converting biomass feedstocks to electricity and heat are currently available. These generally use combustion or biogas production as the basis for energy conversion, but there are also newer systems that use gasification. Cogeneration systems can provide heat for heating, cooling, and other process applications and in doing so they can greatly improve the efficiency of biomass use. By using waste recovery technology to capture the heat that is normally lost during electricity generation, cogeneration systems can achieve total system efficiencies of 60 to 80 per cent.

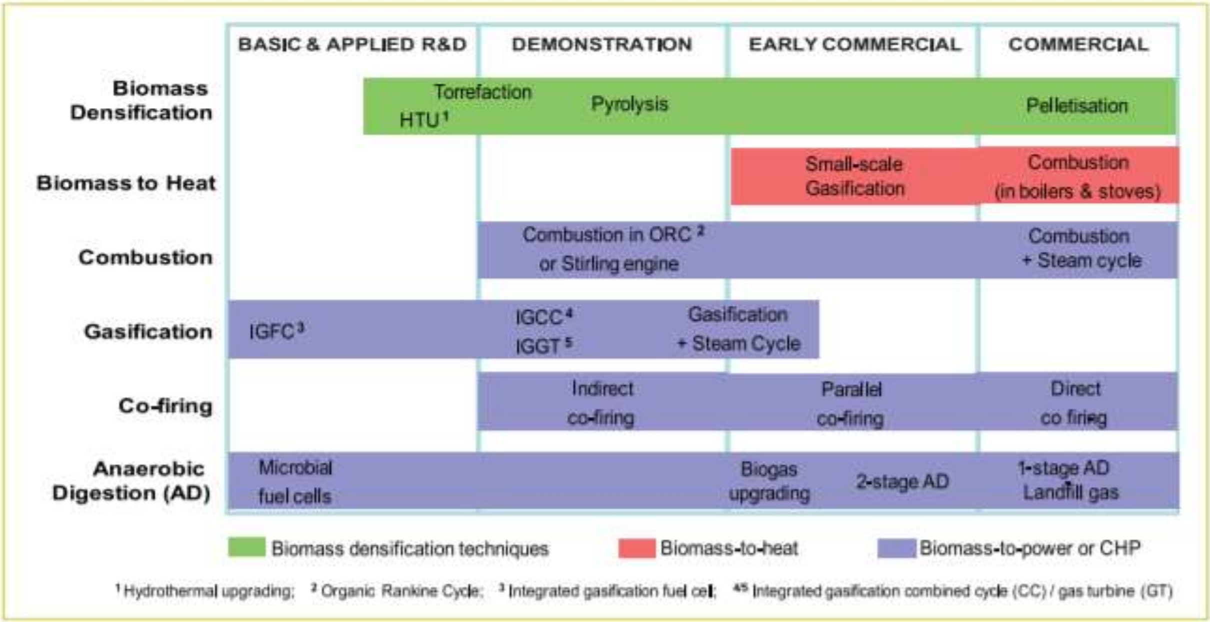


Figure 6: An example of technologies that convert biomass to electricity

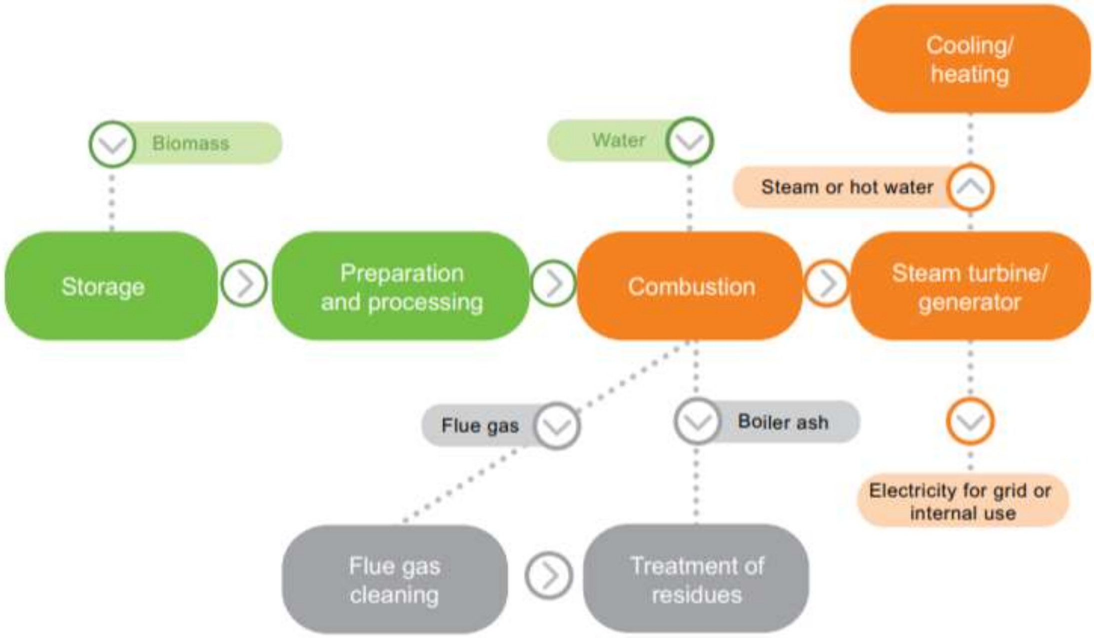


Figure 7: Block flow diagram of electricity generation and heat recovery via CHP
Source: (E4Tech, 2009)

2.1.5. Catalytic Liquefaction

This technology has the potential to produce higher quality products of greater energy density. These products should also require less processing to produce marketable products. Catalytic liquefaction is a low temperature, high-pressure thermochemical conversion process carried out in the liquid phase. It requires either a catalyst or a high hydrogen partial pressure. Technical problems have so far limited the opportunities of this technology (Sharma, Meena, Sharma, & Goyal, 2014).

2.2 Biochemical conversion

The use of microorganisms for the production of ethanol is an ancient art. However, today such microorganisms are referred to as 'biochemical factories' and are used for the treatment and conversion of human generated organic waste. Microbial engineering has encouraged the use of fermentation technologies (aerobic and anaerobic) for use in the production of energy (biogas) and fertiliser, and for the use in the removal of unwanted products from water and waste streams (Jimenez & Lawand, 2000).

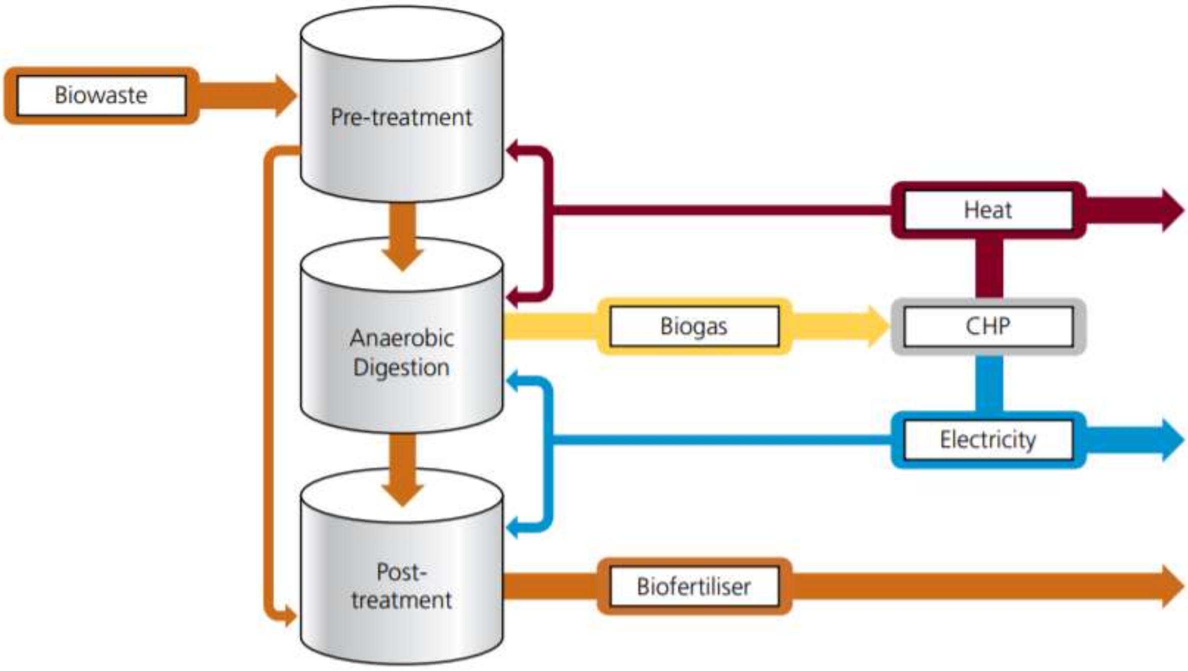


Figure 8: Example of a plant configured to produce energy and buifertiliser from bio-waste feedstock

2.1.6. Anaerobic digestion (Biogas)

Anaerobic digestion, sometimes called biomethanization, is a natural process in which bacteria break down organic matter, in the absence of oxygen, into biogas (mixture of methane, CH4 and carbon dioxide, CO_2) and so-called digestate, a leftover material after biogas production. The biogas can be used directly in cogeneration for electricity production, burned to produce heat or cleaned and used for the same functions as natural gas or as vehicle fuel. Depending on the process, the digestate can often be used as a fertiliser or soil conditioner (DEFRA, 2011). The anaerobic digestion (AD) process can be used with a wide variety of feedstock, including animal manure, crop residues, municipal solid waste (that contains sufficient organic material), sewerage and other waste-water flows that contain organic material that undergo AD (DEFRA, 2011).

Biomass resources play a significant role of energy supply in all developing countries. Biomass resources are divided into residues or to dedicated resources such as firewood and charcoal. Developing countries need to implement measures that increase energy efficiency at levels of generation and demand. It is common practice to dispose this wood waste in landfill, where it slowly degrades and takes up valuable void space. This wood is a good source of energy and is an alternative to energy crops. Agricultural wastes are abundantly available globally and can be converted to energy and useful chemicals by a number of microorganisms. The success of promoting any technology depends on careful planning, management, implementation, training, and monitoring.

2.1.7. Briquette or green charcoal or pellet

Charcoal stoves are very familiar to African society. As for the stove technology, the present charcoal stove can be used, and can be improved upon for better efficiency. This equipment will be of particular interest to both urban and rural households and all the income groups due to the simplicity, convenience, and lower air polluting characteristics.

2.1.8. Improved cook stoves

Traditional wood stoves are classified into four types: three stone, metal cylindrical shaped, metal tripod and clay type. Another area in which rural energy availability could be secured where woody fuels have become scarce, are the improvements of traditional cookers and ovens to raise the efficiency of fuel saving; also, by planting fast growing trees to provide a constant fuel supply. The rural development is essential and economically important since it will eventually lead to better standards of living, and planned settlements.

3 Description of identified sectors and factors affecting conversion technology

In Central African countries, the sectors prioritize for energy supply from biomass energy conversion are represented in the schematic diagram below

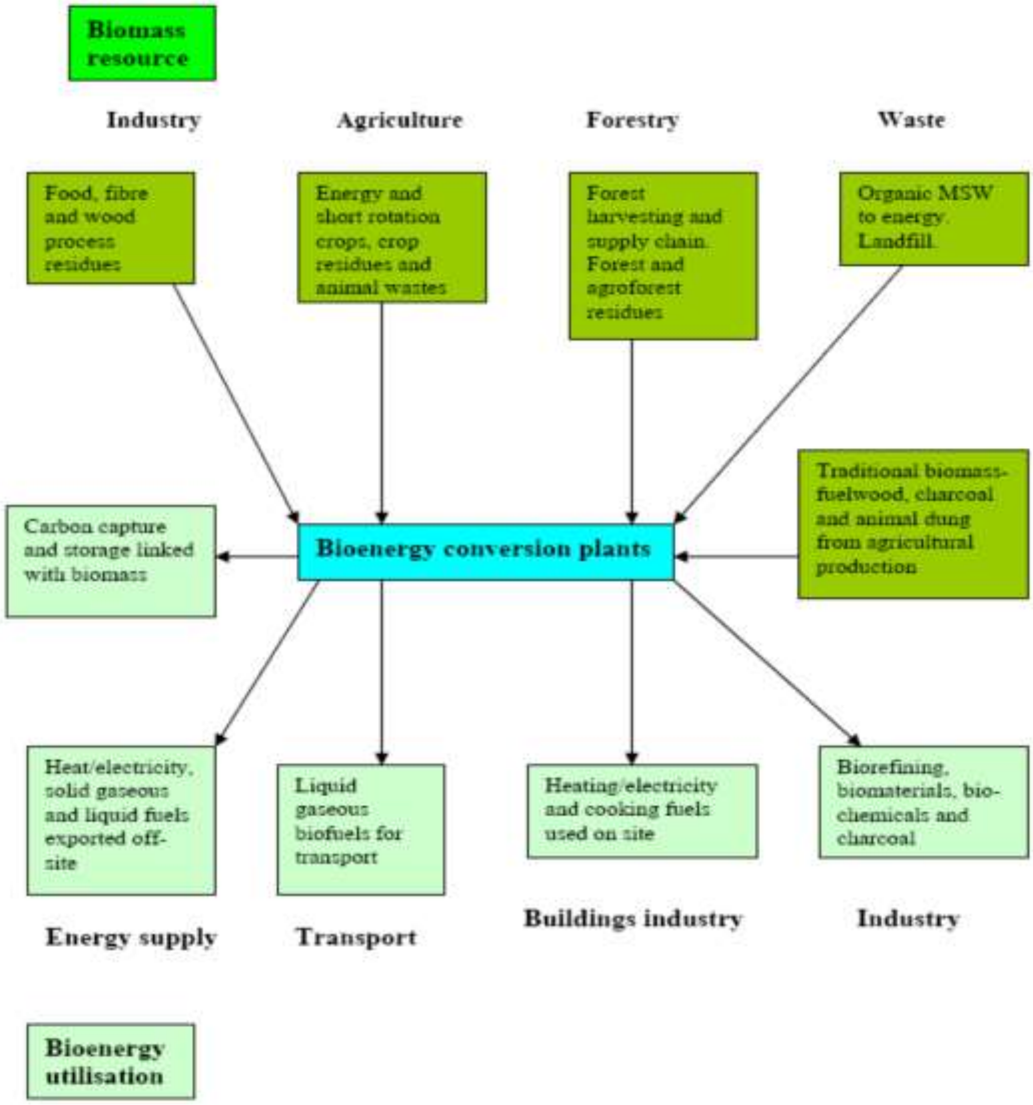


Figure 9: Biomass resources from several sources converted into a range of products for use by transport industry and building sectors

3.1 Republic of Cameroon

3.1.1. Brief description of the identified sector

3.1.2. Industrial sector

The main activities of industrial companies in Cameroon are food products and drinks, wood articles, paper and cardboard articles, refinery products, chemical products, rubber and plastics products, metallurgy and smelting works, metal articles, glass and pottery works, electricity, water and gas. From the results of an inventory on Cameroon's industrial companies carried out by the *Groupement Interpatronal du Cammeroon* (GICAM), an organization grouping company chairpersons and the Cameroon Chamber of Commerce and Industries (CCIC), 80% of Cameroonian industries are located in six cities. These are Douala, Yaoundé, Edéa, Limbé, Kribi and Garoua cities. There are also short-term and long-term industrial projects in the country. Among short-term projects, one can mention the construction of an oil yard in Limbe, the development of an iron and steel industry complex as well as the construction of a deep-sea port in Kribi. There are also expansion plans for the Aluminum of Cameroon (ALUCAM) factory. The letter of intent signed in 2005 between the Cameroon government and the Canadian group ALCAN Inc., proposes the modernization of the current electrolysis tanks and construction of a second series of tanks at ALUCAM factory (UNIDO, 2005; Soderling, 1999; Thomas, Alexis, & Salomon, 2010; EUEI, 2014).

3.1.3. Energy needs of the sector

The development of the industrial sector requires about 400 MW-worth of electric power (ALUCAM 2008). The oil yard being constructed in Limbe *by Chantier Naval et Industriel du Cameroun* (CNI) will require an electric power supply of 20 MW to operate. For some, estimations in the electricity sector development plan (PDSE), stress the need for an additional 3,000 MW of hydraulic power to meet the electricity demand that will stand at 24 TWh in 2025 (Thomas, Alexis, & Salomon, 2010).

3.1.4. Barriers to economic development of the sector

Most of the barriers to development of the industrial sector are:

- Practices in the informal sector (a key finding of the Bank's 2009 Enterprise Survey),
- High taxes and a difficult tax regime, widespread corruption,
- Problems accessing credit,
- Excessive bureaucracy, unfair competition,
- Poor infrastructure, high financing costs,
- Little or no informal dialogue to promote collective action weak energy and water systems,
- Transportation challenges,
- Cumbersome judicial system, problems with training and skills,
- Inadequate labour legislation (World Bank, 2015)

3.1.5. Residential sector

The residential sector is defined as the part of the economy having to do with the places people stay or live. As far as energy is concerned, it considers building designs and end-user equipment. Household buildings include occupied or unoccupied buildings, owned or rented buildings, single-family or multifamily buildings, housing units and mobile homes. End-user equipment includes any equipment, appliance or systems that use electricity or any equipment that causes, controls or influences electricity consumption in the households. The residential sector is characterised by a significant change in the level of household appliances through the effect of development policies and increased household incomes (EUEI, 2014).

3.1.6. Energy needs of the sector

In 2010, Cameroon's total electricity end-use stood at 4,863 GWh. The residential sector represented only 20% of electricity end-use (986 GWh) (AEEP, 2012). With an estimated share of 30% of total energy consumption, the residential sector is the second-highest electric energy consumer in Cameroon. Electricity consumption in the residential sector is characterised by a large discrepancy between urban and rural households. In 2012, household demand on the electricity networks was estimated at 1,113 GWh (EUEI, 2014).

3.1.7. Barriers to the economic development of the residential sector

The Republic of Cameroon has a major problem, which is access to electricity and especially for households in both rural and urban areas. According to the energy situation, there is a gap between energy supply and demand. The residential sector is the sector that suffers the most from unstable supply of electricity. This is because the industrial sector gets more preference in electricity supply than any other sector. The second problem is poverty. The average household income is too low for the members to afford paying for electricity. Most households thus use traditional energy sources such as wood, kerosene and oil that pose health risks. The time spent in collecting wood could be used to engage in other income-generating activities, and the money spent could be better used for other household needs.

3.1.8. Bioenergy resources available, brief description of the quantities

The potential of biomass is estimated to be 6.3 billion tons. However, little seems to have been done about the national modern bioenergy sector. This is evident from the national energy mix where modern bioenergy is almost absent (Ackom, Alemagi, Ackom, Minang, & Tchoundjeu, 2013). Globally, an estimated 72 GW of power generation capacity from biomass was reported in 2011. Moreover, there is an observed increase in the number of worldwide regulatory policies promoting biofuels and globally, the enactment of new laws, expansion of existing mandates coupled with increase in transport fuel-tax exemptions and subsidies (Ackom, Alemagi, Ackom, Minang, & Tchoundjeu, 2013). The agribusiness and wood-processing industries have an annual electricity production potential equivalent to around 700 GWh of electricity. This corresponds to an electricity generating capacity of 140 MW. Developing this generation potential would require an investment equivalent to that of a thermal power plant, but in the absence of adapted pricing and incentives, these projects are not developed. However, the potential is very real (EUEI, 2014).

3.1.9. Description of the technology: Cogeneration

According to the criteria used to assess pilot project studies, Cameroon was selected to consider continuing the pilot project to build a cogeneration unit in Djoum in the South initiated by the forester Rougier.

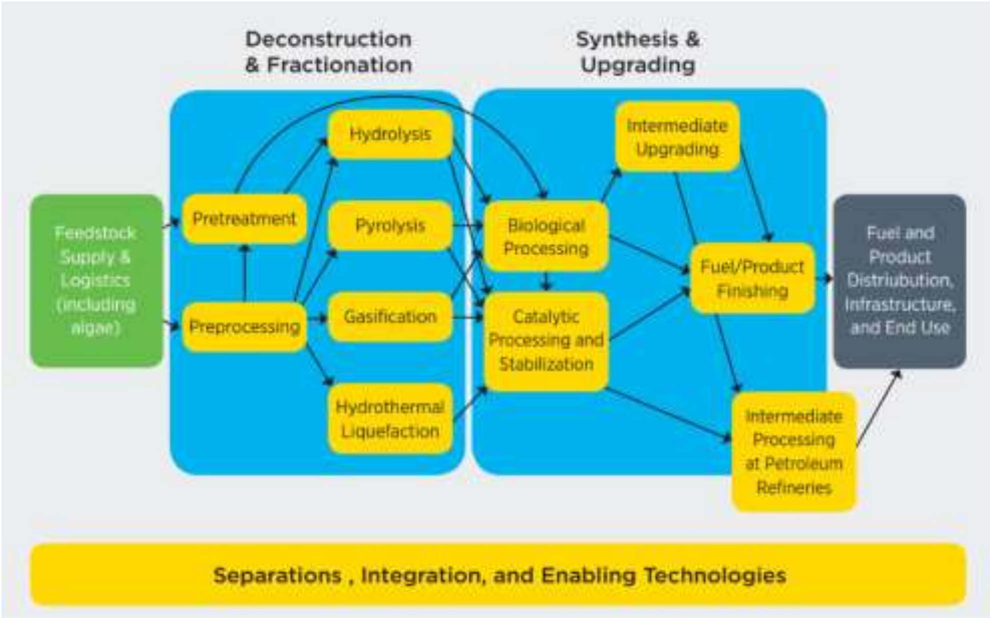


Figure 10: Different technology to convert biomass into energy

3.1.10. Detailed description of the conversion technology including diagrams on how it works

i. Pre-treatment and treatments of the feedstock before being used

When converting waste to alternative energy, pre-treatment is a very important operation that standardizes moisture and waste granulometry. Examples include extraction and fragmentation, shredding, air-drying, grinding in one or two phases on a packaging platform, and screening to remove sand (Prevot, 2010). Overall, unloading biomass from trucks, screening and clearing of biomass, transfer and storage in silos, extraction of silos and transport of biomass to the boiler are the essential steps in pre-processing and packaging of biomass (Biolacq, n.d).

Biomass processing involves introducing pre-treated waste into the boiler followed up by combustion. The combustion will produce either steam or hot water (depending on the type of turbine used). This steam or hot water will spin the turbines for the production of electricity. Smoke and heat from combustion are recovered and processed for heat production (Branca, et al., 2014)

ii. Brief description of the final energy

Cogeneration is a process that allows the simultaneous production of electricity which is then sold to the local distributor. Heat can be enhanced via a heat network for local heat uses such as the production of hot sanitary water using an exchanger.

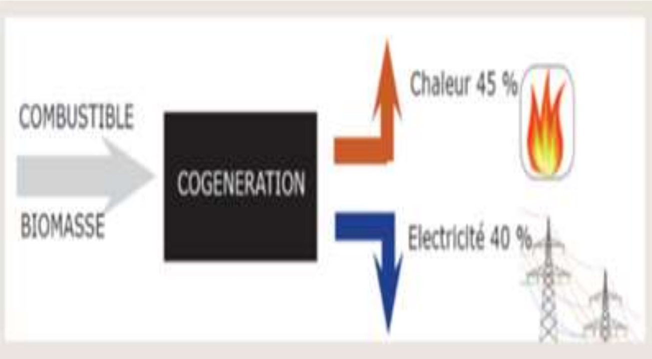


Figure 11: Cogeneration technology

iii. Brief description of consumers how they will access the energy, any challenges and how they will mitigate

In cogeneration, 40-50% of primary energy is found in the form of heat. Some of this heat is used to heat the incoming material and to keep the digester at high temperatures (in the range of 20-30% of the heat). The rest of the heat can be used in different ways such as to heat livestock buildings, technical premises, vegetable greenhouses etc. The final energy users are:

- Households for basic energy needs (electricity, heating, etc.);
- Public services (electricity, public lighting);
- Hotels, restaurants (electricity, heating);
- Health centres (electricity, heating in maternity wards);
- Industries, SMEs;
- Etc.

To access this energy, different user networks request for a tarriff. The tarriff designed is based on the final use of energy. SMEs and or industries have a particular tarriff according to their monthly consumption. Households pay by KWh.

The question of access of the energy transition must be addressed at the outset at different levels of policy-making. Potential barriers to access, especially the cost of renewable technologies, is a key consideration that is particularly critical when implementing household-level technology in poor households. Strong cross-sectoral initiatives between the energy sector and other departments such as the public sector can be a way to develop inclusive energy policies, programs, or subsidy schemes (Johnson, et al., 2020).

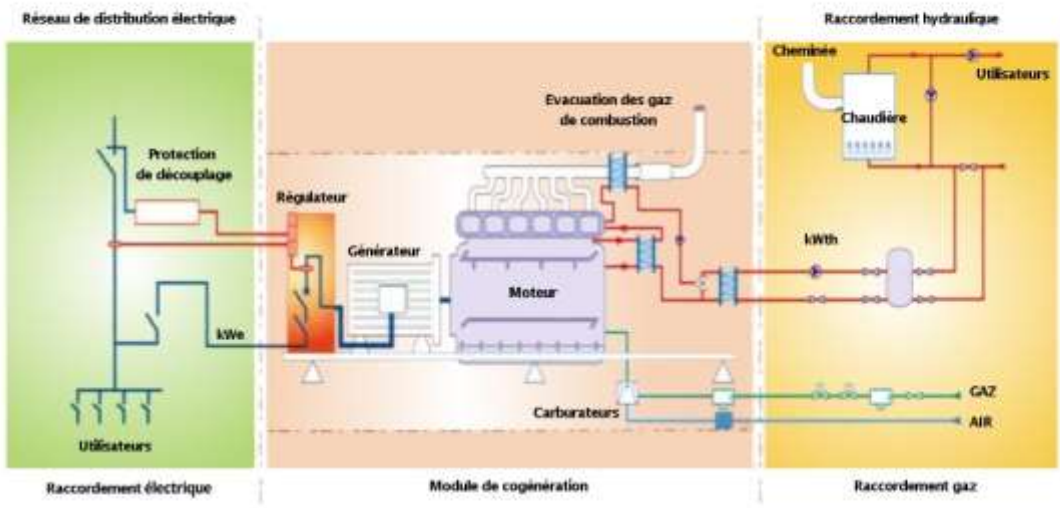


Figure 12: Cogeneration plant

Source: (Johnson, et al., 2020)

3.1.11. Conclusion and recommendation

3.1.12. Areas of improvement on the technology

Cogeneration technologies are using so-called decentralized technologies. This is one of the favourable technologies to enhance access to energy in off-grid areas. The main inconvenience of cogeneration systems is the cost of installation. This requires the support of the government. Several studies have shown that the parameter to be improved is the use of gas turbines. Not only are these turbines economically viable, but they also increase the efficiency of the cogeneration unit. One of the parameters to improve is the recovery and recycling of ash and fumes for other purposes (Somcharoenwattana, Menke, Kamolpus, & Gvozdenac, 2011).

3.1.13. Any policy, environmental or gender recommendations

It is important to conduct gender impact assessments (GIA) alongside environmental and social impact assessments. GIA findings can be used by governments and companies to take affirmative action to combat existing gender injustices. For example, women could be provided with access to certain resources that help ease their transition, officials could develop more holistic compensation plans, or land can be jointly titled in the case of resettlement. (Johnson, et al., 2020). The process of creating and producing technology is a sociotechnical process, where men and women, organizations, culture, and knowledge are combined. Gender is integral to this sociotechnical process. Technology shapes gender and gender shapes technology at every level (Mohideen, 2018).

The aim of an energy efficiency policy/strategy is not to reduce consumers' access to electricity but to improve it. This means not disconnecting economic growth (which should not be compromised on any account) from energy growth. The country will thus benefit from greater energy security and make significant savings in terms of fossil fuel imports. From a macroeconomic perspective, benefits of an energy efficiency policy should not be limited to the timely and temporary resolution of Cameroon's current problem of balancing supply with demand in the field of electricity. Many benefits will arise from the establishment and implementation of a national strategy to increase energy efficiency, and in particular (EUEI, 2014):

- the improvement of the reliability of the electricity supply through bringing the level of consumption below the generation capacity while maintaining the same level of service for end-users,
- The reduction of the use of emergency or back-up units using fossil fuels,
- Reductions in polluting emissions and, in particular, greenhouse gases, linked to the use of fossil fuels,
- The improvement in the standard of living of Cameroonian households, notably through the reduction of their electricity bills

3.2 Republic of Congo

3.2.1. Industrial sector

During 2017 and early 2018, the management of industrial activity issued approvals in accordance with the provisions of Law 9, of 18th July 2015, which organised industrial activity. Around 43 industrial units were allowed to be established in 2017. In terms of location, the Pointe-Noire department leads the way with 26 industrial units in 2017 followed by Brazzaville with 14. In the first half of 2018, there were four industrial units authorized to set up shop, including three units in the Pointe-Noire department and one unit in the Pool Department. Activities concentrate on the production of dairy products, paint, coating and adhesive, soaps, detergents, toiletries and palm oil refining (MEI, n.d.).

Table 1: different type of industries in Republic of Congo

Sous-Secteur	*Entreprises*	*Filières*	*Branches d'activités*	*Produits fabriqués*
Industrie de produits alimentaires	301	17	14	37
Industrie boissons	34	7	3	11
Industrie matériaux minéraux	32	5	3	17
Industrie produits a base de tabac	1	1	1	1
Métallurgie	28	3	3	13
Industrie de produits chimiques	25	8	3	13
Industrie d'ouvrages en métaux	26	3	2	28
Industrie d'articles d'habillement	4	1	1	2
Industrie d'autres materiels de transport	3	2	2	2
Industrie de machines et d'équipements n.c.a	1	1	1	1
Industrie de meubles et matelas	17	3	1	7
Industrie de papier, cartons et d'articles en papier ou en carton	11	3	1	8
Imprimerie et production d'enregistrements professionnels	14	3	2	6
Industries du caoutchouc et du plastique	17	1	1	21
Réparation et installation de machines et d'équimenents professionnels	28	2	2	17
Industries de produits pharmaceutiques	5	1	1	5
Travail du bois et fabrication d'articles en bois hors meubles	31	1	1	8
Travail du cuir, fabrication d'articles de voyages et de chaussures	1	1	1	1
Autres industries manufacturières	3	2	1	2
TOTAL	582	65	44	209

3.2.2. Energy needs of the sector

Finally, demand for natural gas accounts for 11% of energy demand. This demand arises from the utilization of the gas to produce electricity and LPG (butane and propane) for domestic and industrial purposes. Electricity is consumed to power production equipment (Constantine, Aymard, Donald, Patrick, & Jean-Claude, n.d).

Industries generally consume high- and medium-voltage currents. Generally, plants operate during the day and for some sectors 24 hours a day, such as the oil, cement and industries with large-scale refrigeration facilities. Consumption will evolve into two (2) phases: between 2015 and 2020, it will increase from 2,055,309,426.72 kWh to 3,073,604,548.6 kWh, an increase of 1,018,295,121.89 kWh (49.5%). From 2021 to 2025, consumption will increase from 3,332,091,295.35 kWh to 4,296,289,446.20 kWh, an increase of 964198150.85 kWh (28.9%) (Constantine, Aymard, Donald, Patrick, & Jean-Claude, n.d).

3.2.3. Barriers to economic development of the sector

There are many tariff and non-tariff barriers. With regard to non-tariff barriers, there are import restrictions on certain products. These are accompanied by domestic price controls, which, far from promoting the expansion of internal supply capacity as originally envisaged, they instead slow them down. This factor causes recurrent inflations and, sometimes the state is forced to subsidize for social reasons, with a negative impact on its budget. Numerous tax cuts, customs fees imposed on export and import products limit the development of the industrial subsidiary (Republic of Congo, 2017). In many oil-producing countries, non-price factors such as lack of basic infrastructure, and government corruption and red tape often pose more formidable obstacles to growth in the non-oil sector than price-related factors, including developments in the real effective exchange rate (Guidal, Herail, & Rosenstock, 2018).

3.2.4. Residential sector

Households are classified as residential consumers. They mainly use electricity for their lighting. Households are the largest consumers of electricity. They consumed 50% of total consumption in 2011 according to statistics from the SNE network. Moreover, this category of consumers is the main factor in increasing installed capacity. A large share of household electricity consumption usually takes place in the late morning and evening to meet lighting needs. Other equipment that consumes electricity at the household level are mainly television, radio, household appliances, etc. Among these, the refrigerator stays connected at all times (Constantine, Aymard, Donald, Patrick, & Jean-Claude, n.d).

3.2.5. Energy needs of the sector

In Republic of Congo, the structure of energy demand is made up of biomass, hydropower, petroleum products and gas. The main segments of the energy market are individuals (households), industries - SMEs/PMIs, transport, agriculture, and government.

Electricity consumption from households is largely represented by households connected to the SNE grid. Considering an increase in the total number of households according to the current population growth rate (2.6%), with the maintenance of the current electricity access rate of 45% and the level of electricity consumption, total demand would is then estimated to reach 4 604 944.72 MWh in 2020 and 5 934 571.36 MWh in 2025 (Constantine, Aymard, Donald, Patrick, & Jean-Claude, n.d).

3.2.6. Barriers to the economic development of the residential sector

The Republic of Congo, like some countries in the Congo Basin, has a major problem, which is access to electricity and especially for households located in rural areas. In the report on the situation of energy demand, it mentions that there is a large gap between energy supply and demand. The residential sector suffers the most from unreliable electricity supply. This is because the industrial sector receives more preference in power supply than the residential sector. The second problem is poverty where the household average income is too low to afford electricity and therefore the household is forced to use traditional fuels such as wood, kerosene, and oil that are harmful to their overall health.

3.2.7. Bioenergy resources available, brief description of the quantities

Biomass is the country's most popular source of energy, accounting for 81% of Congo's energy supply. This subsector is mainly provided by small producers, mainly households whose operation remains traditional modes of cooking and heating. The supply or production of biomass consists mainly firewood and charcoal. This biomass comes mainly from forest by-products (woodcut, forest waste, wood industry waste). Biomass accounts for between 4 and 10% of Congo's energy supply. In 2008, biomass primary production and final consumption was 0.72 Mtoe and 46 Mtoe respectively (Constantine, Aymard, Donald, Patrick, & Jean-Claude, n.d).

Congo is largely covered by forest (60% of the national territory) which accounts for 10% of all tropical rainforests. The potential biomass productivity for Congo's tropical forests is among the highest in the world. The total supply of primary energy in Congo is estimated to be 2637 Ktoe, while the total final consumption amounts to 1769 Ktoe. Biomass, mostly distributed in the forms of firewood, charcoal, forest waste, sawdust and chips, accounted for 65% of total final consumption.

3.2.8. Description of the technology: Congo Carbo industry (CCI)

CCI will use new carbonization technologies to improve quality and increase quantity of charcoal production. Advanced kilns will increase the efficiency of carbonization, doubling it by comparison to the traditional mound kilns and unimproved kilns commonly used in the Congo today. Here we describe the three technologies that CCI will use, none of which is currently in use in the Congo.

3.2.9. Detailed description of the conversion technology including diagrams on how it works

i. Pre-treatment and treatments of the feedstock before used

Waste pre-treatment consists of sorting to eliminate non-biodegradable waste, grinding to have homogeneous granulometry and drying to reduce water content to optimize yield.

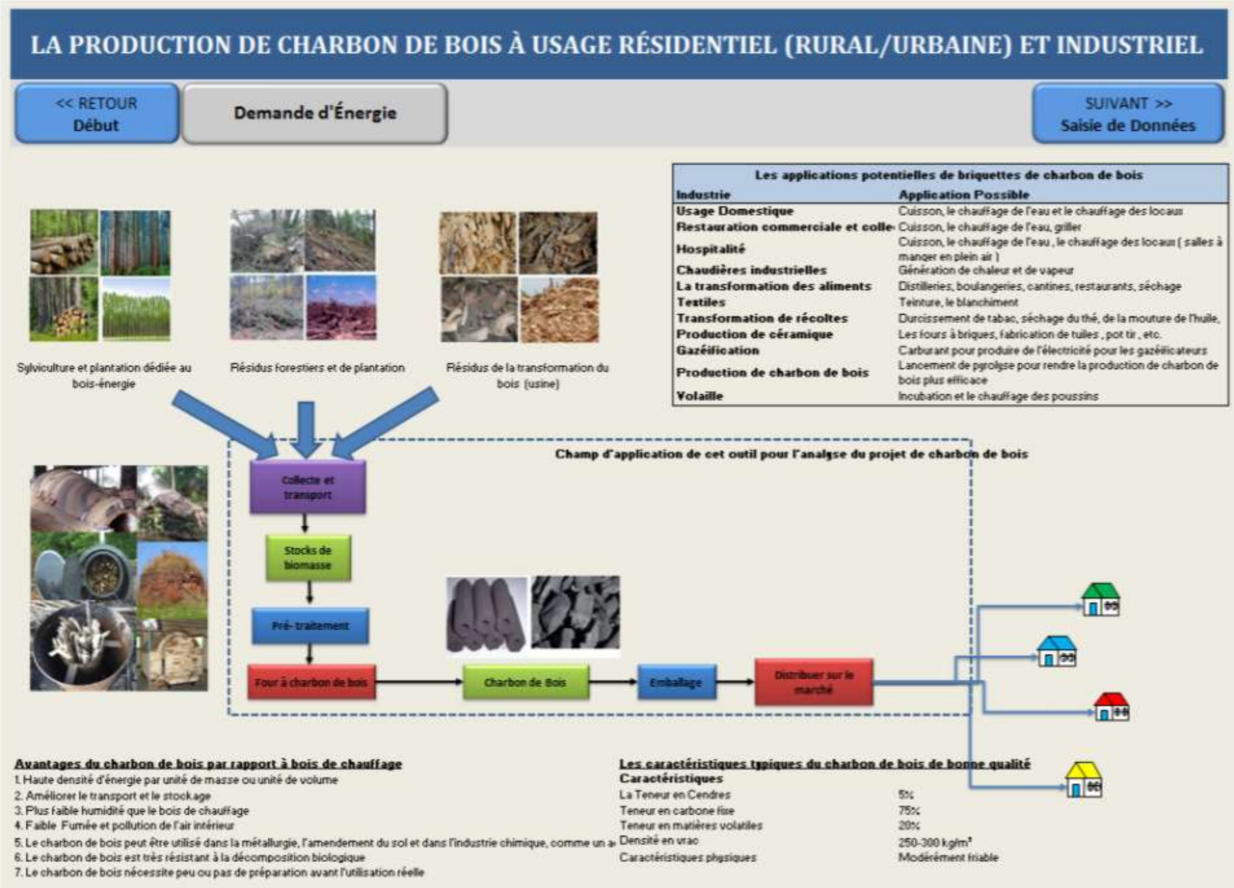


Figure 13: Charcoal system for heating and cooking in rural and urban areas

Source: (Branca, et al., 2014)

Green Mad Retort (GMDR): The Green Mad Retort Kiln (GMDR) is a semi-industrial brick retort kiln. It was initially developed in Madagascar to produce charcoal from Eucalyptus wood harvested in local plantations for the same use as proposed by the CCI project. The GMDR consists of three parts: external combustion chamber, where lower quality wood or other biomass may be used, charcoal chamber, and chimney that includes a simple system that allows the post-combustion of the gases generated by the carbonization. The GMDR has double walls that ensure an airtight seal during the cooling phase. This carbonization technique produces up to 35% charcoal yields, by mass, when used with wood at the appropriate moisture content (Guidal, Herail, & Rosenstock, 2018; Herail & Guidal, 2018).

CML process with Industrial Retort Kiln: Industrial production plants using the CML process consist of a standardized unit comprising 4 or 12 cylindrical retorts kilns that are all connected together to a post-combustion furnace prior to the chimney. It uses the heat produced by the combustion of the pyrolysis gases for drying purposes (e.g., of fuelwood) or to produce electricity. The CML unit allows the carbonization of all types of wood, including deciduous and resinous, providing significant flexibility in woodstock. The carbonization efficiency (in yield and productivity) is directly linked to the quality and characteristics of the raw material used (particle size, humidity, cleanliness, etc.). Charcoal is produced in cylindrical retorts fitted with a lid at the top and a discharge hatch in the base (Guidal, Herail, & Rosenstock, 2018; Herail & Guidal, 2018).

Charcoal briquettes: Charcoal briquettes ('charbriquettes') are combustible briquettes made of carbonized biomass material. Dust particles of charcoal, known as 'fines', are bound together and compressed. Charbriquettes require a binding agent, usually starch from maize, cassava or rice, which accounts for 5–10% of unit weight. Charbriquettes behave and burn very similarly to charcoal, requiring users to change neither stove nor practices. Their main advantages compared to charcoal are that they have a longer burning time, do not produce sparks, are somewhat less polluting and offer consistent quality (Guidal, Herail, & Rosenstock, 2018; Herail & Guidal, 2018).

ii. Brief description of the final energy

Charcoal briquettes ('charbriquettes') are combustible briquettes made of carbonized biomass material. Charbriquettes behave and burn very similarly to charcoal, requiring users to change neither stove nor cooking practices. Their main advantages compared to charcoal are that they have a longer burning time, do not produce sparks, are somewhat less polluting and offer consistent quality.

iv. Brief description of consumers how they will access the energy, any challenges and how they will mitigate

In 2014 average consumption of woodfuels was 0.21 and 0.12 kg/day per person for firewood and charcoal, respectively. This is against a consumption of 0.79 and 0.15 kg/day per person respectively for firewood and charcoal 20 years prior (Boundzanga 2014). Firewood is dominant in rural areas, while charcoal is more prevalent in urban areas, typically because of transport and other costs. Projected trends in population and urbanization would suggest that demand for charcoal, relative to firewood, continues to rise. Average charcoal prices seen on the domestic market (January 2018) range between 160–200 FCFA/kg in PointeNoire and from 220 to 250 FCFA/kg in Brazzaville. Experience shows that even with better quality, it takes time to sell a new charcoal product at significantly higher prices than common market rates. In the meantime, the product should have a price that is stable and able to accommodate future economic shocks. A price of 300 FCFA/kg for 'green' charcoal or charbriquettes would suffice as the best price after considering profits and future price increases.

3.2.10. Conclusion and recommendation

3.2.11. Areas of improvement on the technology

Improved charcoal production technologies are largely aimed at attaining increases in the net volume of charcoal produced as well as enhancing Its quality. A large proportion of charcoal production in developing countries like Congo is carried out as a semi-illegal part-time activity since the wood used is often illegally procured. Consequently, few charcoal makers are willing to invest in improved charcoal kilns since they would be vulnerable to punitive official measures such as imposition of tax and seizure. Consequently, increasing the uptake of improved charcoal techniques in the informal sector has proved to be a difficult undertaking.

3.2.12. Any policy, environmental or gender recommendations

Wood plantations and land concessions will be the main source of renewable raw material and energy. The size of plantation is significant since it will determine the sustainable provision of raw materials at an industrial scale(see estimates in annex 3). However, the greater the scale of production, the greater the potential for negative social and environmental impacts. Downside risks include environmental, degradation, pollution and diminished livelihood options for local peoples.

According to interviews with key informants, women are marginal actors in the Congolese charcoal supply chain. Traditionally, women are primarily involved in the trade of charcoal. It expected that because of the volume of production, CCI would require an aggregation of supply-chain actors, which may unintentionally marginalize the roles of women.

3.3 Democratic Republic of Congo

3.3.1. Brief description of identified sector

3.3.2. Industry sector

The industrial sector accounted for 5.6 per cent of GDP in 2003. Formerly of considerable size, today it consists of a few small plants producing textiles, food, chemicals and capital equipment. All industrial branches have suffered from a financial crisis that has affected the country for a number of years. Manufacturing industries, cut off from their sources of raw material supply and markets for their finished goods, currently use only 15 to 17 per cent of installed production capacity. To make the country's industrial sector more competitive, the government has launched a programme to reform public enterprises, under the aegis of the steering committee for reform of public enterprises (COPIREP). The reform targets the mining, transport, energy, telecommunications and financial sectors in particular. Mining, energy, water and transport enterprises are the dominant forces in the production system, but the state is heavily indebted and unable to assume its role of promoting economic activity. The current period of political transition is, however, not propitious for the privatisation of public sector companies, as there is opposition to the "squandering of national assets". The country has adopted new investment, mining and forestry codes that afford operators and investors more fiscal incentives, guarantees and transparency (Kabemba, 2005; World Bank, 2018).

3.3.3. Energy needs of the sector

The residential sector comes first (57%), followed by losses inherent in energy processes (37%), the industrial sector takes third place (2.8%), followed by transport in fourth place (2.5%) and agriculture, fisheries and forestry are the last in the ranking (0.1%). The following table shows the energy demand in the industrial sector.

Table 2: Energy demand in industrial sector

Item	unit	2005	2010	2015	2020	2025	2030
Industry							
Low growth	GWh	2 490 326	3 449 192	5 742 639	9 800 528	17 141 430	30 947 732
Basis growth	GWh	2 490 326	4 441 712	15 984 283	15 984 283	31 904 305	62 529 135
High growth	GWh	2 490 326	5 031 886	21 847 773	21 847 773	49 918 929	121 220 333

Source: (Esseqqat, 2011)

3.3.4. Barriers to economic development of the sector

Major obstacles to the development of industry include lack of technical and managerial skills, difficult access to financial resources and most importantly, lack of financial security. There is very little demand for sub-contraction on the part of large firms. As a result, the industrial sector is hardly participating at all in the development process. The technology is obsolete and productivity very low. They have neither accounting systems nor any real financial and organisational discipline, and their average lifetime is five years. In addition, the steady decline in living standards has led to explosive growth of the informal productive sector, reflecting household survival strategies (Kabemba, 2005).

The biggest obstacle facing the industrial sector is financing. They cover their capital requirements through advances from customers, family and friends. The country's industrial development pales in comparison with Cameroon and other countries in the region. Banks grant no loans whatsoever to SMEs. An SME department has been formed within the Ministry of Industry, but its financial resources are paltry given the scale of the sector's requirements (Kabemba, 2005).

3.3.5. Residential sector

As in other countries in the Congo Basin, all households in rural, urban and peri-urban areas constitute the residential sector of the DRC. The urban and peri-urban areas have the most households. The main household activity in the DRC is agriculture. Residents of urban areas in the DRC have an established practice of urban agriculture. Poor households use their residential plots to grow maize and vegetables, primarily for household consumption. Residents also cultivate on public thoroughfares, hilly areas, and basins within the urban perimeter. Peri-urban areas are often devoted to farming. The residential sector ranks as the top energy consumer. However, analysis of the energy situation shows that there is a large gap between supply and demand in this sector. This is justified by the fact that the number of households grows with the population.

3.3.6. Energy need for the sector

More than 57% of the energy produced in the DRC is consumed by the residential sector . Wood and charcoal are the main sources of energy. The table below shows the past trends in energy demand for future projections for the residential sector.

Table 3: Energy demand in residential sector

Item	unit	2005	2010	2015	2020	2025	2030
Household							
Low growth	GWh	2 201 082	4 135 048	11 480 187	18 497 992	28 155 558	48 781 342
Basis growth	GWh	2 201 082	4 925 434	11 640 764	22 809 205	39 462 932	68 740 595
High growth	GWh	2 201 082	7 515 363	23 185 713	32 525 276	50 672 589	80 958 709

Source: (Esseqqat, 2011)

3.3.7. Barrier to economic development of the sector

Like other African countries, the residential sector in DRC has the same challenge of access to reliable electricity. This problem equally affects households in both the rural and urban areas. In DRC, energy produced is preferentially distributed to industries, especially to those in the mining sector. As a result, the residential and other sectors suffer from an insufficient supply. Poverty resides in most households. Many households in the country have a low average income. This does not allow them to pay for electricity and therefore they use wood, kerosene, oil and many other traditional fuels that have high health risks. The time spent and money spent in collecting wood and other fuels robs the resources that could be used to enhance other income-generating activities.

3.3.8. Bioenergy resources available, brief description of the quantities

The DRC has approximately 125 million hectares of forest representing 67.9% of the country's land area. For cooking and other household purposes, firewood and charcoal are the main biomass fuels used. However, these fuels are inefficient and pollute the environment. According to 1985 data figures, the consumption of these fuels accounted for 8.5 million toe (ton oil equivalent), or 86% of the total energy used in the DRC. Wood and charcoal account for 75% and 25% of these fuels, respectively (Kusakana, 2016).

3.3.9. Detailed description of the conversion technology:

The type of ICS disseminated for usage will be microgasification cookstoves burning fuelwood pellets. Microgasification cookstoves burn woodfuel very efficiently and cleanly. Microgasification cookstoves produce their own gas from solid biomass in a controlled manner. Gas generation occurs separately from subsequent gas-combustion. Since wood gas is burned, microgasification cookstoves are nearly as clean as LPG stoves.

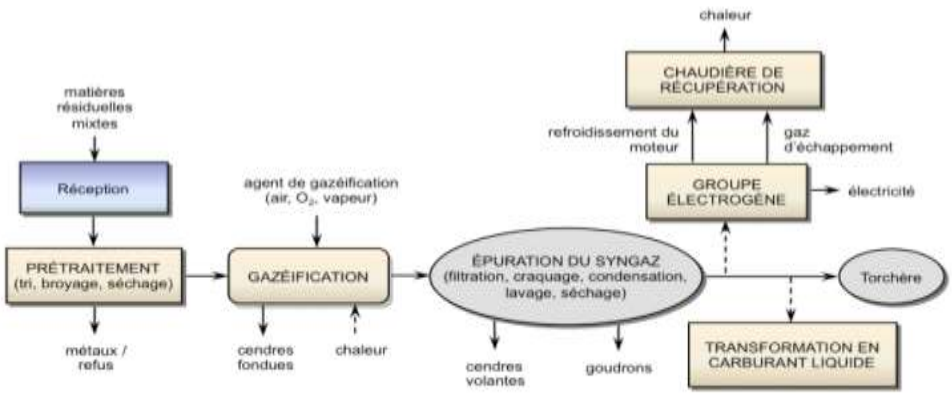


Figure 14: Typical flow pattern of a gasification process with or without cogeneration and heat unit

i. Pre-treatment and treatments of the feedstock before used

For this type of improved microgassing fireplace, pellets will be used as fuel. Therefore, waste from the exploitation of wood will be used for pellet production. Sawdust, chip, branches, heart defects, and other tree parts will be used. This waste must be pre-treated. Pre-treatment consists of sorting, grinding and then removing the unwanted material.

ii. Brief description of the final energy

The final product will be wood pellets that resemble a small cylindrical stick of grinded and compacted wood waste. Sawdust and shavings are mostly used. Its length is around 4 to 6cm; its diameter is about 5 mm; its density is 650 kg/m3; its calorific value is around 4,8 Mwh/t.

iii. Brief description of consumers how they will access the energy, any challenges and how they will mitigate

Given the energy situation, there is increasingly intense energy demand from households, which exerts further pressure on forests. The potential consumers of pellets and microgasification cookstoves include low-income households (urban and rural areas); middle-income households (urban and rural areas). In the industrial sector, the mining and pastry industries are potential users. Households have returned to purchase the pellets directly either from the resellers or from the manufacturing plant. A kilogram of pellet costs Fcfa 200. The cost of pellets per kilogram could be subsidized as a proportion of the amount of waste that a customer brings to the factory or sellers. Similarly, the cost of microgasifier stoves will be lowered if customers bring organic waste to buy pellets at discounted prices. Further customer service can include home delivery of the pellets or microgasifier stoves at the customer's expense. The payment will be made either in cash or by wire transfer. The cost of selling the pellets to the industrialist will be a function of the quantity requested and the type of partnership.

3.3.10. Conclusion and recommendation

3.3.11. Areas of improvement on the technology

A few publications concerning wood pellets with additives have been published before and in the following section are extensive reviews of some of them. Researchers from Sweden focused on reduction of nitrous oxides by using additives in their work. Experiments were conducted with a 90kWh boiler with pressurized fluidized bed combustion. To achieve lower nitrous oxides emissions values, additives of sodium carbonate (Na_2CO_3), ammonium bicarbonate (NH_4HCO_3) and urea were used. Straw, willow and sawdust were used as fuel. Only urea had the effect of reducing nitrous oxides. Another research work from Denmark involved applying various additives into biomass. The additives were mixed with the fuel directly on the grate. It was found that the effects of additives also depend on the combustion technology used. Test results showed that it is possible to burn wheat straw with wood chips, olive stones and shea nuts. During the experiments, there were no serious problems associated with deposition and corrosion. The report concluded that burning of straw together with high-quality coal might reduce corrosion and formation of ash in the boiler (Holubcik & Nosek, 2012).

3.3.12. Any policy, environmental or gender recommendations

Several research articles indicate that there are environmental benefits of using wood-based biofuels for residential heating. These benefits can be further enhanced when the biofuel is produced locally to minimize the costs associated with importing the same. Although this report focused primarily on the impacts of carbon, there are several other environmental impacts from fossil fuels, such as smog, respiratory effects, and ozone depletion.

The negative effects of traditional solid-fuel cooking on gender equity are apparent. Women bear a disproportionate burden of the costs associated with firewood collection such as physical injury from the heavy loads, animal attacks and sexual molestation (World Bank, 2014).

3.4 Republic of Burundi

3.4.1. Brief description of the sector identified

3.4.1.1 Domestic / Institutional sector

Burundi is a small, densely populated country emerging from twelve years of socio-political conflict. Though this is positive, the country continues to face severe food security and nutrition challenges. Burundi is one of the most resource poor, low income and food deficit countries worldwide. According to the 2014 Global Hunger Index report, it is also experiencing the highest levels of hunger in Sub-Saharan Africa, with a global index score of 35.6. The 2014 UNDP Human Development Report ranked Burundi 180 out of 187 countries with widespread poverty level of 90–95%. Majority oof the population, especially in the rural areas, lives on less than USD 2 per day (WFP, 2016).

The national income per capita is about $260, which is one of the lowest in the world. About 90% of the population lives in rural areas, although the urban population has rapidly grown in the past decade. A majority of Burundian households rely on biomass for most of their energy needs. Households are the main consumers of energy in the country, accounting for 94% of total national energy consumption. Household needs are almost exclusively and entirely met by traditional biomass. Statistics put the dependency of households on biomass at 99%. A high population density combined with unsustainable use of biomass and inefficient cooking methods, such as the use of three stone hearths is making fuelwood a scarce commodity. Efforts to replenish tree cover through reforestation face competing interests of preference of using idle land for agriculture. It is estimated that only 6% of the country's total land area is forested.

The World Bank estimates the national access to clean cooking solutions at <1% (SE4All, 2020). Burundi's Vision 2025 has as a principal objective to ensure that by 2025 both the rural and urban populations have access to reliable, clean sources of energy and at competitive prices. Burundi's Intended Nationally Determined Contribution (INDC) also seeks to have 100% of traditional charcoal kilns and traditional home ovens replaced by 2030. It is therefore critical to establish a bioenergy project that meets the needs of the domestic sector and also falls within the long-term national objectives.

3.4.1.2 Energy needs of the sector

More than 90% of the population in cities and almost 100% of secondary urban centers use charcoal or firewood as cooking fuel. Thus, in Burundi, natural resources are generally declining due to two factors: a rising population that exerts pressure for more agricultural land for food production and a considerable annual deficit ratio of 1:3 between the supply and demand of wood energy.

A high population growth together with rapid depletion of natural resources strains the national budget of the country. Therefore, there is an increasing urgency to harness alternative sources of energy apart from fossil fuels to meet current and future demand of the country. Even though a majority of households and communities depend on firewood for cooking, their energy consumption practices are not environmentally sustainable. Over 86% of the country's households use the traditional three stone hearth for cooking and boiling water. This method has very low energy efficiency. Around 85-90% of the energy is lost to the atmosphere using this method. An additional 7% of households and communities use traditional mud stoves while only 7% have access to improved cookstoves. Firewood accounts for over 96% of the total national consumption. Majority of the users are in rural areas (76%) compared to urban areas (24%). With such a high dependency on firewood for domestic purposes, there is always a deficit on firewood supply annually. Since the use of biomass energy will likely persist as the primary source of energy in the rural areas, it is worth assessing how cheap, wood-based solid fuels can be used as a reliable alternative energy source.

3.4.1.3 Barriers to economic development of the sector

According to the National Development Plan (NDP) (2018-2027) energy deficit is considered as one of the major constraints to the country's socio-economic development. According to the NDP report, the Government of Burundi (GoB) identified three strategic objectives for the economy: the first objective is to ensure sustainable and inclusive growth for economic resilience and sustainable development. Stemming from this objective, the second strategic pillar focuses on building appropriate infrastructure to support energy production and also promote renewable energy (World Bank, 2019). There are also several available sources of waste biomass and agricultural residues all over Burundi, but which remain largely unexploited.

A World Food Program (WFP) study in 2016 (WFP, 2016) highlighted limited access to clean energy sources as one of the reasons households fetch firewood for their domestic heating, cooking and lighting needs. The use of firewood was not only a health risk to the household members, but it was also time-consuming activity that robbed households from being involved in income generating activities. Furthermore. It contributed to truancy in schools where children would help in collecting firewood as opposed to being in class. A second contributing factor is the high poverty rates in the country. Most households are not able to afford clean household fuels and thus resort to using three-stone hearths and other solid fuels.

3.4.2. Detailed description of the conversion technology and the project

Project name: Sustainable Bioenergy Cooking Solutions for rural and urban Households in Bujumbura Province through production and distribution of pellet-fed semi-gasified cookstoves and wood fuel pellets.

The proposed project is built on the success of Inyenyeri, a social enterprise currently active in Rwanda (Inyenyeri, 2020). Based in Gisenyi, Rwanda, the social organization currently distributes the Mimi Moto forced-draft, pellet-fed semigasifier cookstove through a business model that claims to emphasize customer service and affordability. The Mimi Moto is currently the best-performing wood fuel cookstove according to lab-based measurements (Clean Cooking Catalog, 2020). Therefore, it offers the potential to drastically reduce indoor emissions (and exposure) compared to traditional solid fuel stoves. There is no similar initiative existing in Burundi but there is potential to try a similar technology with a few modifications based on the needs of the customer.

Figure 15: Diagram showing an advert of the Inyenyeri stove

3.4.1.4 Pre-treatment and treatments of the feedstock before being used

Wood pellets will be produced from the by-products of wood processing industries (sawdust or wood shavings) or from forest residue collected from Gakara-Gahuni Forest in Bujumbura Province. Because of an additional drying process, biomass pellets made from the wood feedstock offer up to 3100kCal/kg energy content as compared to raw wood which offers much less. This makes the pellet a viable substitute to charcoal. In the pelleting process, forest biomass residue mostly from fallen branches, uprooted trees, sawdust, pole production waste, girdles and slashed napier grass is shredded and then compressed using a specialized pelleting machine; this process is energy intensive and therefore electricity is used to power the entire production process. An example of the pelleting process is provided below.

Figure 16: An example of pellets

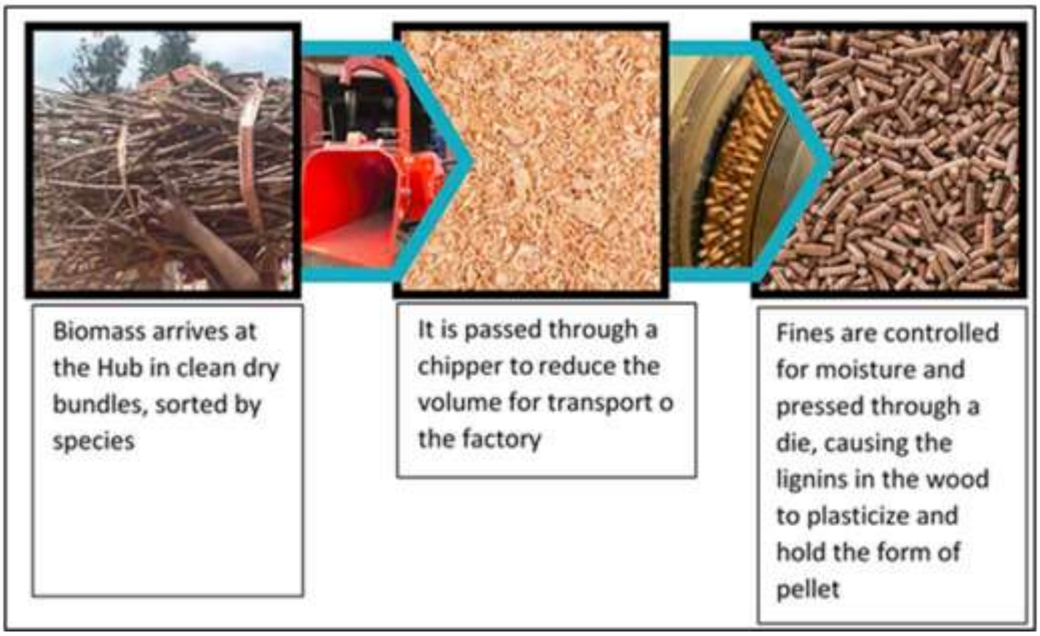


Figure 17: Pelleting process used by Inyereri

3.4.1.5 Brief description of the final energy

Wood pellets are the end product of the entire process. The nearest and largest market for these pellets is the residential sector of Burundi. The manner of supplying cookstoves to the customers will heavily rely on the lessons learnt in Rwanda which has experience on a similar project. The use of pellet-based gasifier stoves provides a viable step in household transitions toward cleaner energy and in general, reduce the amount of greenhouse gases emitted from traditional fuels. Pellets are fuels of homogeneous quality that reduce the inherent variability in size, shape, and moisture content associated with most solid fuels (Champion & Grieshop, 2019). A study conducted by Wathiora et al., on ICSs in Malawi (Wathore, Mortimer, & Grieshop, 2017)found that heterogeneity in fuel quality and loading was a key factor for reduced performance of forced-draft ICSs. Therefore, homogenous fuels, such as pellets are recommended to increase operational efficiency of ICSs.

3.4.1.6 Brief description of consumers challenges and how they will be mitigated

In Rwanda, customers in Inyenyeri sign a monthly contract to purchase pellets. The prices of pellets are competitive to the market rates of charcoal. Apart from the stove, customers are entitled to regular training, fuel delivery and free repairs.

Key facts from the work of Inyenyeri company work in Rwanda (Inyenyeri, 2020):

- **A free lease of the cleanest, most efficient biomass cookstoves**. In return, customers agree to buy wood pellet fuel from the company.
- **Anyone can be a customer**. Urban women buy their fuel pellets with cash, while rural customers trade raw biomass for pellets.
- **Save money from day one.** A Rwandan family typically spends about $21 to cook for a month with charcoal, but only about $14 with Inyenyeri.
- **Rural customers need to collect only half as much wood as before.** That saves 30+ hours a month, exposing women and girls to less security risk, and leaving more time for work and education.

- **100% Risk and Hassle Free.** No cost to sign up, and customers get as many stoves as they need to completely replace their old way of cooking. An additional benefit free lifetime repair and replacement.
- **Free training and delivery.** With SMS and mobile money, customers get free fuel delivery to their door via bike taxi, plus lifetime upgrades on their stoves.

3.4.3. Conclusion and recommendation

3.4.1.7 Areas of improvement on the technology

A recent study in Rwanda on Mimi Moto cookstoves show that when operated incorrectly, pellet-fed gasifier stoves may emit as much greenhouse gases as traditional wood and charcoal stoves. Therefore, it is prudent to thoroughly train buyers on their correct use. The study highlighted the importance of using kerosene as opposed to kindling when operating the cookstoves. Customers are also urged to monitor their stoves during refuelling, towards the end of their cooking, and to properly dispose the pellet char after use as opposed to letting it smoulder. From the positive results observed in Rwanda in a similar venture, and the business model of Inyenyeri continuing to be refined and documented, the ICS enterprise in Burundi may be able to offer customers similar health and climate benefits compared to other cooking fuels, and also reduce the socio-economic constraints that most households face in accessing clean cooking fuel.

3.4.1.8 Any policy, environmental or gender recommendations

The proposed project has huge potential in contributing to Burundi's NDC targets. The project will also support the country's efforts to increase household access to affordable, viable bioenergy technologies that can contribute to achieving the country's clean cooking targets. The project also has gender benefits as illustrated in Section 3.4.1.6 above.

3.5 Burkina Faso

3.4.4. Brief description of the identified sector

3.5.1.1 Domestic/industrial/trade and services sector

Cashew has become Burkina Faso's 5th largest export product. Cashew is considered, at the level of national development policy, one of the main priority areas. The area in 2015 was 255,000 hectares, mostly in the southwestern part of the country. By 2020, production reached 100,000 tonnes. (Comité Interprofessionnel de l'Anacarde du Burkina, 2018). In 2019, the country has processed nearly 10,000 tonnes of raw nuts per year, or 10% of production, and these volumes are expected to increase steadily in the coming years. This is the plan for the Cashew Initiative, a flagship project implemented by the Conseil Burkinabè of Anacarde and its partners, which plans to increase the national rate of nut processing to 45%. In particular, 20 new nut processing units are expected to be built by 2024 with the support of this project. Investors have been on the move in 2020 and there are several industrial processing units that started this year.

Most of the new plants are born in Bobo-Dioulasso, the capital of the Country's High Basin region, located in the heart of the cashew plantation area. Indeed, the city enjoys good connections with the rest of the country as well as the railway which facilitates the flow of goods to the port of Abidjan. The second area of concentration of the transformation is the Cascade region. The cashew sector, apart from being a source of employment and stable income for more than 45,000 nut-producing households, provides jobs on the processing link: according to the CIAB, 10,000 direct jobs are mobilized by the ten or so processing centres in operation in the country, of which nearly 90% are occupied by women.

The most processing plants tend to be located in industrial areas and are therefore surrounded by other players in Burkina Faso's manufacturing fabric: processors of agri-food products, textile industry, building materials.

3.5.1.2 Energy needs of the sector

Industries in the southwestern part of the country, particularly the agri-food industry, have energy needs in the form of electricity but also heat. Agribusiness units often have an installed unit capacity of one to a few hundred kW **and** therefore pay for energy at the most expensive tariffs in the country; while the price of kWh in Burkina Faso is already one of the highest in Africa. (Global Petrol Prices, 2020) Thermal energy is sometimes supplied by the agri-food waste itself; this is the case for the cashew or shea industries.

In cashew processing plants, about 70% of the nut as a starter to the plants becomes waste. The bulk of this weight corresponds to the hull, which is only valued in small proportion (10-15% of the hulls) as fuel within the plant; however, this does not avoid raising questions about the relevance of this method of value,as we point out below.

There is a growing interest in the use of this waste by other neighbouring production units. This is the case for cotton oil refining or fruit drying units, which take advantage of the waste shells of cashew units. In fact, the cashew shell is a heat fuel and can be burned as it is, making it a good substitute fuel for wood, which industrialists continue to use in their boiler rooms. However, this application of the hull finds its limits in the harmfulness of the fumes emitted during direct combustion. Indeed, the direct combustion of the hulls releases corrosive substances and the chimney fumes of the factories are therefore pointed out as a source of nuisance and air pollution. This is why the use of the hull is still far from widespread, while the deposit is large and constantly growing.

As noted in Report 2.1, which reported the locations of residual biomass, with volumes processed in 2019, 11,200 tonnes of hulls would be available for valuation because they were not otherwise valued; and by 2030, if the assumption of 45% of national production is processed (200,000 tonnes planned), that would be 50,400 tonnes of hulls to be valued. Not to mention other dry biomass deposits also available, such as shea cakes produced by industrial units often located in the same industrial areas.

If such fuel is available in large quantities in industrial poles consuming electricity and heat at the same time, the opportunity to generate electricity from this biomass seems attractive at first glance.

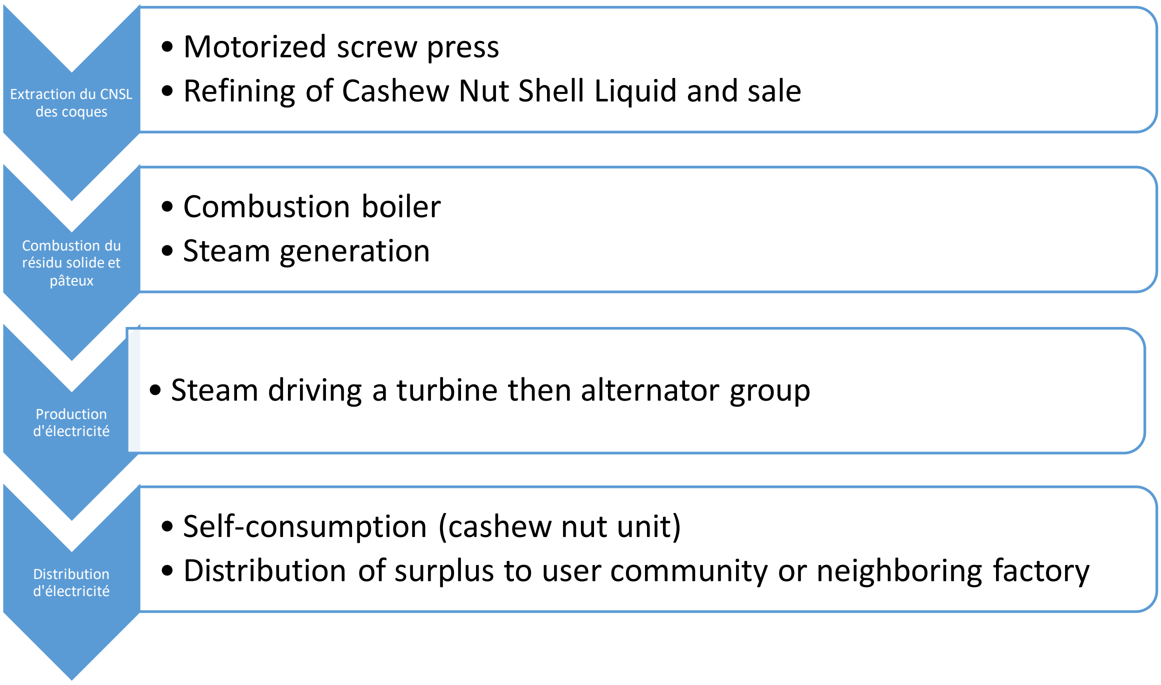
3.5.1.3 Challenges to the sector's economic development

The stakes around the cashew shell do not stop there: without real economic recovery, this waste becomes a burden for processing units, and an additional risk to bear. It is also an element of competitiveness vis-à-vis Asian competitors who value all hulls, and can count on this source of revenue.

The increasing trimming of the sector by the installation of new factories will inevitably come with the corresponding increase in the generation of hulls, now neglected of the productive circuit. Indeed, small and large units, all are looking for sustainable patterns that can absorb and give value to these waste materials. Now that the cashew industry is taking off, and the political will is strong, it is time to consider solutions for the treatment of hulls that take into account the processing sector in all its diversity.

3.4.5. Description of technology and operating scheme

First, the hull must be cleared of the oil contained. This liquid, known as Cashew Nut Shell Liquid (CNSL), is contained in the hull to the tune of 20 to 25%. It is a liquid, although commonly called oil, which is not edible. It is also causing smoke problems during combustion, and the irritating nature of the shells to the touch. It is nevertheless a valuable substance, because from the CNSL it is possible to manufacture various products, in the field of paints and polymers but also active substances as pesticide, and finally as liquid fuel (because it is comparable to heavy fuel oil). The extraction of the CNSL is carried out by extrusion of the hulls in a screw press. The CNSL must be decanted and refined to become a marketable product. The residues that result from these treatment processes can be energy-efficient, starting with the solid residue after the extrusion of the hulls, called cake.



3.4.6. Pre-care of biomass upstream to be valued

As explained in 2.1 above, it is advisable to separate the CNSL from the woody part of the hulls, for several reasons:3.4.5 above

- The CNSL can be sold with an interesting value as liquid fuel, serving heavy industry (metallurgical, cement) or small industry (bakeries). The value obtained for this material is greater than the value of solid biomass.
- There is a good chance that the CNSL will generate problems in the energy conversion system (soiling, tar clogging, soiling of moving parts, corrosion of joints and weak materials, etc.), which complicates the operation by increasing the costs of O and M, and could force the choice of materials resistant to this substance, therefore more expensive.
- The CNSL has the potential to be a source of other high-value added products (not just fuel). Therefore, from the point of view of optimizing the valuation of matter, it is advisable to leave open the possibility that the CNSL is available for other uses (polymer, resin ...), which can be more interesting from an economic point of view.

Once the CNSL is extracted, the meal is no longer dangerous to the machines and the liquid can be valued on another track depending on market demand.

3.4.7. Description of the final energy product

The conversion of the meal by cogeneration as described above therefore produces recoverable energy in the form of electricity and heat.

The distribution of energy (thermal and electrical) produced will depend to a large extent on the administrative arrangement of the biomass conversion unit. The most attractive option is for the plant operator to be a mixed entity composed by biomass suppliers (cash mills and possibly others). In this case, the costs of supplying raw materials are minimal, and biomass producers are involved in the sharing of electrical and thermal energy. This operator will have a status ofself-producer. In Burkina Faso

law, theself-production of electric power consists of the production of electricity mainly but not exclusively for its own use (Government of Burkina Faso, 2017). In this context, the car-producer will be able to sell or transfer its excess electricity to an eligible distributor or customer under a purchase' auto-contract. The production unit will use some of the electricity to run the CNSL extraction facility and then export the surplus to neighbouring plants, depending on the purchase contracts.
The biomass conversion site should be as close as possible to one or more heat consumers. What can be cashew units, or other industrial units demanding heat at low temperature.

3.4.8. Consumer description (profile, energy product access arrangements, potential challenges and how this should be mixed)

Consumers are industrialists in the area. Whether it is food processors (oilseeds, fruits, flours) or other (cement, metallurgy, polymers...). In the ideal arrangement, industrialists involved in the supply of raw materials (biomass) will have priority of access to electricity. This energy can be shared de facto on the basis of the gross energy contribution at the entrance, which promotes the balancing of interests with the benefits provided by access to cheaper energy. First, it would be the cashew processing units that would benefit. But other waste can be valued in these facilities, such as shea meal (available by thousands of tons annually in the same area).).

3.4.9. Conclusion and recommendation

3.5.1.4 Improved technology

The choice of conversion technology can obviously affect investment and operating costs, but also thermal/electric energy yields and even by-products. This is why the needs of the beneficiaries must be best characterized. Gasification technology could also have the advantage of producing coal as a by-product, with sales benefits to the populations of this material.

3.5.1.5 Recommendations at the political, regulatory, environmental, gender level

Given the sustained production figures of national orchards in recent years, compared to the low processing rates in the country, it is highly likely that the cashew still has enormous, untapped potential, to bring even more added value to the country than it currently does. In this sense, a pilot project installed near one or more cashew processing units can become **a** replicable example in the other development poles of the country and contribute to the sustainability and competitiveness of the cashew industry, strategic for the country.
The main recommendation is the choice of beneficiaries and operators of the pilot recovery unit. It is highly recommended that they be actors with a strong presence in the country and a pragmatic vision on access to energy. The best case study seems to be that of the Anatrans plant, in the northern industrial area, which has been running continuously since 2013. Anatrans is currently the largest unit in the country with a processing capacity of 10,000 tonnes by 2020. Neighbouring it is a second cashew plant that has just set up shop, and two shea butter extraction units that could eventually join the project and become stakeholders.

3.6 Republic of Côte d'Ivoire

3.6.1. Brief description of the identified sector

3.6.1.1 Agriculture sector

The Ivory Coast, with a population of 19.9 million, two-thirds of whom depend on agriculture, is showing sustained growth in all its economic sectors, including the agricultural sector, which accounts for 28% of the country's GDP (MAF, 2019). The southern half of the country, where dense wet forest once dominated, enjoys a Guinean climate that allows for a diversity of crops, in addition to conventional logging. The economy of the people who live there therefore relies particularly on the exploitation of these fertile lands and the forest currently available. However, the Ivorian population is no longer predominantly rural. Today, the urbanization rate of the Ivory Coast is around 52% and has been increasing at an average rate of 1.5% in the past decade. This reflects a change in living standards, but also a diversification of economic activities from agriculture to manufacturing, industrial or service fields. However, far from wanting to deviate from land-related activities, the country intends to increase the market value of its agricultural assets. One of the ways to do this is through value-addition of its agricultural residues. For decades, cocoa has been the country's main agricultural export. Cacao exports from Côte d'Ivoire meet 40% of the world's consumption. Cultivation of this crop is the main occupation for 20% of the population (Le Monde, 2020). To actualize some of the agricultural development strategies, the government intends to raise the amounts of processed cocoa to 100% of the total harvest by 2025. At the same time, the government will put in the requisite measures to ensure fair remuneration to farmers and increased yield and quality of the cocoa fruit.

3.6.1.2 Energy needs of the sector, biomass resources available

Households in Côte d'Ivoire account for 60% of the country's energy consumption. As reported in Report 3.1, the sector is the largest user of biomass. For example, in 2017, the total amount of biomass used at household level was 3763ktoe, which by energy sources used, accounted for 88% of the national total. At household level, on average 89% of the energy comes from biomass, compared to only 7% from petroleum products and 5% from electricity.

Despite the government's efforts to promote different forms of cooking fuel apart from firewood, biomass still remains to be the largest source of household fuel in the country. Households use biomass mostly in the form of firewood and charcoal. The dense forests to the south provide the people with fairly abundant forest biomass. The Guinean climate experiences high precipitation levels and this part promotes dense forest growth. Crops that grow in this climatic region include rubber, teak, oil palm, coffee, and cocoa. These plantation trees provide people with not only commercially viable agricultural products but also fuel at the end of the crop life. Indeed, plantation wood is often found in markets alongside other felled forest species and packaged in form of wood bundles or even charcoal. Households are the main buyers of plantation wood while the productive sector, bakeries in particular, prefer to source denser wood from endogenous species.

However, the biomass collected from tree plantations does not represent the total usable biomass volumes in the country. There is always a significant volume of non-woody biomass waste that is uncollected from the fields. This is the case with cocoa, where for every 1 kg of market beans the weight of pods is 13 kg. The dried pod, which would have a weight equivalent of 2 to 3 kg per kg of market beans, has proven to be a raw material suitable for carbonization.

3.6.1.3 Challenges to the sector's economic development

Demand for charcoal has been rapidly rising in the country. This is due to the country's increasing urbanization and rising income levels especially in the major towns. The rising demand for charcoal in proportion to an expanding population has put considerable pressure on forests which are targeted by charcoal sellers to exploit them for more firewood and charcoal. According to recent investigations carried out in the region of La Mé, the wood to be charred for charcoal mainly comes from old fallows and thinned cocoa plots, or sometimes from different crops in other fields[1].

At the same time, in recent years, due to soil degradation exacerbated by deforestation, cocoa yields have been on the decline. The cacao tree is a light-sensitive tree that requires rich soils to maintain productivity. It is only in recent years that the promotion of shaded cocoa, also known as agroforestry cocoa, begun. If the government stops the clearing of forests to create space for cacao cultivation, the action will have a ripple effect where conversion of forestland for other agricultural purposes will also reduce. This will also preserve the soil fertility of the fields. Research has shown that there are links between low cacao prices and deforestation, and if farmers will keep cultivating the cacao.

It is from these findings that some civil groups are attempting to find a solution that is financially appealing to farmers, and at the same time, preserves both the forest cover and current cultivation of the crop. After some investigations, the concerned groups found that the cortex, which is the empty part of the cacao pods, was normally disposed by farmers and left to decompose in the fields. However, the cocoa pod contains waste that can be valorized and used as an energy source. Spreading the cacao pods as humus, compared to leaving them in idle heaps, had the advantage of releasing nitrogen back into the soil. Both both the cacao trees and the farmers benefit from this, as opposed to losing nutrients to air by decomposition. Open air decomposition of plant materials is a major contributor of greenhouse gas emissions - methane and nitrous oxides.

3.6.2. Description of technology and operating scheme

Each producer co-operative will have one or more carbonization sites and will oversee the entire carbonization process. The cocoa cortex is charred in metal barrels, in a layout similar to that in the figure below. The charred product is removed through the lower door and loaded into watertight drums for cooling. Through the carbonization process, a pyrolytic liquid, also called pyrolinen, is extruded and is also used as a phytosanitary treatment against pests. The charred pods will then be transported to the briquettes production unit.

The central unit is to be located in an urban center and in close proximity to a wood processing unit (sawmill) that will supply some of the raw materials.

In the central unit there will be an infrastructure suitable for charring sawdust using a rotating carbonizer. The rotating tool mixes the sawdust with residues collected from the surrounding cocoa plantations.

The process of making briquettes begins with the grinding of charred materials to a particle size acceptable to the press. Then, depending on the power of the press and the desired final consistency of

[1] *Bioenergy diagnosis in the Region of Mé. R. Aouaké, D.Gomeu, A.Guhur, R.Vaudry (Nitidæ, 2019)*

the briquettes, a binder is added, and the paste is thereafter mixed with water. The binder used in the experimental phase was cassava starch recovered from nearby cassava processing units. A symbiosis will then be established between the briquettes manufacturing unit and the cassava processing centers so that the cassava waste is supplied to the briquetting sites.

Figure 18: Pyrolysizers for carbonizing cocoa cortexes

Source: Nitidae

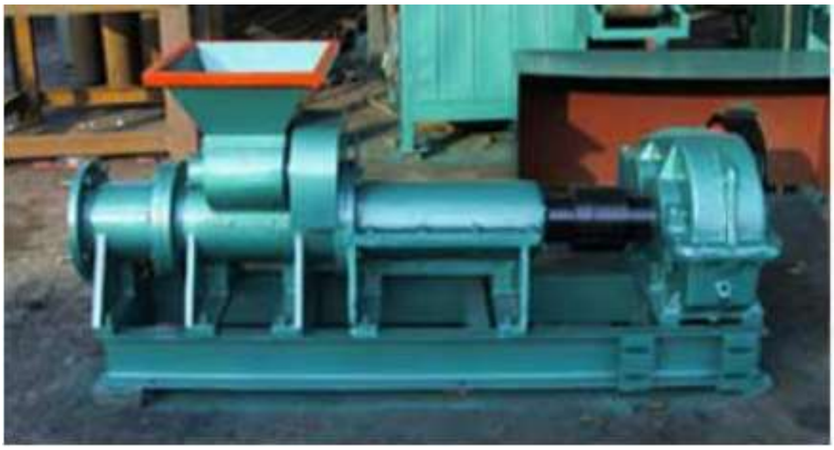


Figure 19: Small capacity briquetting press

Source: Maxton Engineering

The mixture will be inserted into the briquettes press for compaction. The briquettes will have to dry in the sun for some time to be ready for collection. In order to optimize the drying of the briquettes it is planned to set up a greenhouse-type structure where ventilation and air temperature will be controlled. This structure will be able to entirely operate on solar energy.

The diagram of the biofuel manufacturing process is presented below.

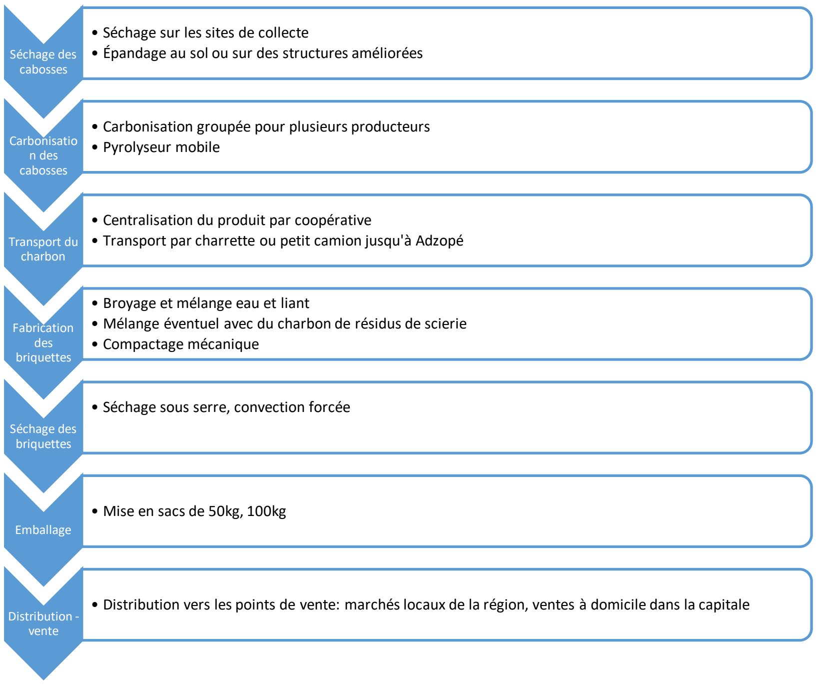


Figure 20: The biofuel manufacturing process

3.6.3. Pre-processing biomass upstream to be converted

By pre-processing we mean the upstream processes of the key conversion stage which include carbonization. Indeed, both pods and sawmill waste retain a certain degree of moisture. They must then be dried until they reach proper humidity to become carbonized. The lower the humidity, the higher the carbonization yield.

In the case of cacao pods, they are spread out on drying mats or surfaces. The same infrastructure used for drying and fermentation of beans can also be used to dry the pods. However, the drying surface will need to be increased given the large volume of pods and the fact that the two operations may overlap over time.

Drying of chips and sawdust requires specific equipment, which is normally included in the package proposed by the supplier of the carbonization equipment of these materials.

3.6.4. Description of the final energy product

The final product is a plant-based coal that is produced from local agricultural and forestry waste. The briquetting technique developed will ensure that the characteristics of this charcoal are more superior to that of conventional charcoal, and thus have a competitive advantage than those currently in the market.

3.6.1.4 Consumer description and related challenges

The target consumers are the average income households within the urban areas. The product will be made available in the charcoal selling outlets, so as not to give any image of the product's exclusivity. Furthermore, the strategy seeks to ensure as large a number of people in urban areas are aware of the new product. To increase the rate of community adoption, advertising campaigns will be done to reach the entire population and educate them on the product.

A key target for the briquettes will be Abidjan which is a major market center for charcoal produced from the surrounding region. The capital also offers better prices for charcoal than other areas in the country. The strategy there will be to market the product to the upper- and middle-income households and where possible, offer home delivery to the customers.

In order to elicite interest, this project will cooperate with existing clean energy programs on the ground to disseminate the new charcoal product. This will reinforce the positive impacts of both parties and their products (combustion equipment, and fuel).

The program will have to source for dedicated cocoa producers to maintain a consistent supply of cocoa pods. To reduce the financial risks that may arise from low sales of the improved charcoal, a quota of biocoal will be reserved for the cacao producers as a form of remuneration and to shield them from total loss. In addition, they will be provided with the pyroline fluid produced during carbonization. Awareness campaigns and agricultural expositions will be facilitated by partner cooperatives to introduce these two new products to both cacao farmers and end-users. Finally, there are concerns that collection of the cocoa pods might deny the soil of humus which previously was from cocoa pods left behind after harvest. The project through its agronomic support and supply planning component will have to ensure a rational collection of the cortexes from its suppliers, so as that the suppliers (farmers)are left with some pods to leave as humus in the fields. The process of decomposition return nutrient back to the soil and is important in completing the nitrogen cycle.

3.6.5. Conclusion and recommendation

3.6.1.5 Improved technology

The carbonization technique developed so far by the Association of Natural Forest Owners and Plantations of Afféry (APFNP) has the advantage of being locally designed, easily portable and does not require an external power source to operate. These qualities make it suitable for field use by cocoa producers. However, there is still room for improvement in ergonomics (easy loading and maintenance), performance (carbonization time, efficiency) and material durability.
The small size of the APFNP unit optimizes the drying speeds of the cortexes and charcoal briquettes at the input and production stages, respectively. This will reduce the need for charcoal stockpiles that diminish in quality upon absorbing moisture when exposed to air.

3.6.1.6 Recommendations at the political, regulatory, environmental, gender level

From various sources that have made proposals in the field (R.Aouaké, D.Gomeu, A.Guhur, & R.Vaudry, 2019) (PNUD, 2013), several actions are to be implemented in order to create an environment fully favorable to domestic fuels from plant biomass:

- Assess the sustainability of the resource (wood and non-wood forest energy products), using the new National Forest Inventory and a specific study on intra- and inter-regional fuel biomass flows. This exercise is essential for planning, on a rigorous scientific basis, the sustainable exploitation of forest biomass. It will employ the REDD framework to implement measurement, notification and verification systems that will also help to map the carbon impact of these activities.
- Promote, through lean formalization mechanisms, the formalization of the activity of charcoal or firewood producers, both local and foreign, wishing to work legally in these sectors. It is also proposed for the creation of organizational bodies that would facilitate exchanges between producers and the administration, to enhance transparency in the management of logging permits, and also take into account non-woody products being used for energy purposes, such as cocoa cortexes, in order to regulate their exploitation.
- It would be necessary to structure coal miners, firewood operators and bio-charcoal players in a legal way to a single inter-professional body capable of bringing its voice into the negotiating table with the administration.
- Clarify the legal framework so that producers of agricultural-based charcoal are not classified in the same category as conventional charcoal or firewood operators, and the authorities to also tax them differently, if not less by virtue that their work is 'green'.

3.7 Republic of Mali

3.6.6. Brief description of the sector

The country's energy consumption is dominated by biomass: 65% of total final consumption in 2017, 90% for the residential sector and 10% for the trade and public service sector. As a result, the residential and commercial sectors (grouping income-generating activities) are the main sectors with potential for bioenergy. (AFREC, 2019)
Of its more than 20 million inhabitants, about a quarter are believed to live in the Bamako wood-energy supply basin. According to the Bamako City Domestic Fuel Supply Scheme (SDACD), produced in 2017, about 5.5 million people live in the supply basin of the city of Bamako (which includes the original rural municipalities of wood and the population of the city of Bamako currently close to 2.8 million). The city's population grew by nearly 5% between 1998 and 2015. In order to meet the demand from the urban area of wood-energy, wood removals are increasingly carried out in the formations of woodlots of cultivated fields such as shea parks (Vitellaria paradoxa) or forage trees (e.g. Faidherbia albida) and more only "classic" forest formations such as savannahs or steppes. (FONABES, 2017).

The main economic and industrial hub of the country, the capital concentrates not only a growing population but also various economic activities of importance to the Malian economic fabric. About a quarter of households in Bamako district report economic activity in the household. For the vast majority, it is small catering: selling hot meals, porridge, donuts, etc., which uses wood fuels, preferably coal but also firewood. In addition, the economic activities traditionally consuming wood: bakery, dyeing (bazin), dibiterie and meat grilling for sale...
Outside the city, households have agriculture as their main activity (91% according to SDACD surveys). Apart from that, virtually all households engage in economic activity within it. Surveys indicate that 98%

are involved in the collection and processing of shea nuts (non-wood forest products), and the same percentage more or less regularly cook condiments for sale. They all use firewood to these effects.

Given the important challenge of the availability of wood-energy for these populations, and given the observed and growing lack of wood biomass, it seems relevant to meet the needs of the residential sector but also the trade sector, intrinsically linked, with a pilot project for the conversion of forest biomass.

3.6.7. Energy needs of the sector, biomass resources available to supply the sector, reasons for action in this sector

3.7.1.1 Energy needs of the sector

Traditional biomass, including firewood and charcoal, is largely the main fuel used by the population to meet its energy needs, at 96% among households and 86% in the trade and utilities segment. Due to population growth and low forest productivity, there is a strong imbalance between the supply and demand for energy wood, especially in the supply basins of major cities, such as Bamako, whose current deficit (2015) has been estimated at about 490,000 tonnes of wood (according to the Bamako SDACD, published in 2017). The projection for 2025 presents an annual negative balance sheet of more than 2,000,000 tonnes of wood-energy (see result 2 report); this justifies the use of alternative bioenergy sources and modern/improved cooking methods. (AFREC, 2019)

With regard to non-wood forest products, one of the most relevant sectors in terms of energy-efficient residues generated appears to be shea butter. The transformation of nuts into shea butter, practiced in a generalized way by the populations, leads to the production of nuts and cakes.

The wood-energy consumption of rural populations around the Bamako district accounts for more than 70% of the consumption of populations in the Bamako supply basin. Only 30% of consumption corresponds to the urban population. In many municipalities, the consumption of local populations is now higher than the production of wood. The average rural consumption hypothesis is one stere or 330 kg per capita per year.

For Bamako and its supply pool, the annual consumption of domestic energy for 2015 is recorded in Table 4 below.

Table 4: Annual consumption 2015 urban and rural households in the Bamako supply basin, in thousands of tonnes

	Bamako	Urban municipalities	Rural communities
Firewood	350,24	174,65	987,24
Charcoal	177,91	76,53	-
Butane gas	15,83	6,81	-

In terms of raw energy, wood-energy consumption would amount to 34.5 PJ, or 857 ktoe, of which 35% goes to Bamako and 65% is consumed by the supply basin. Firewood accounts for 52% of Bamako's consumption, but by intensive consumption of wood in rural communities, it accounts for 84% of the consumption of its supply basin. For coal, the figures are 39% and 15% respectively and the LPG is 6% and 1%.

In terms of economic activities, bakeries in the city are by far the largest consumers of woody energy, in the form of firewood. They are followed by dying and dibiteries. Outside the district of Bamako, the most common income-generating activities are the treatment of shea nuts with its traditional processing (roasting and churning) and cooking condiments for sale. In Figure 21 below, the raw energy consumed by each of the economic activities in the city is provided. The consumption of economic activities in the rural area has only been summarily studied, however, we can remember that for the scalding of 1 ton of shea nuts it is necessary 640 kg of firewood.

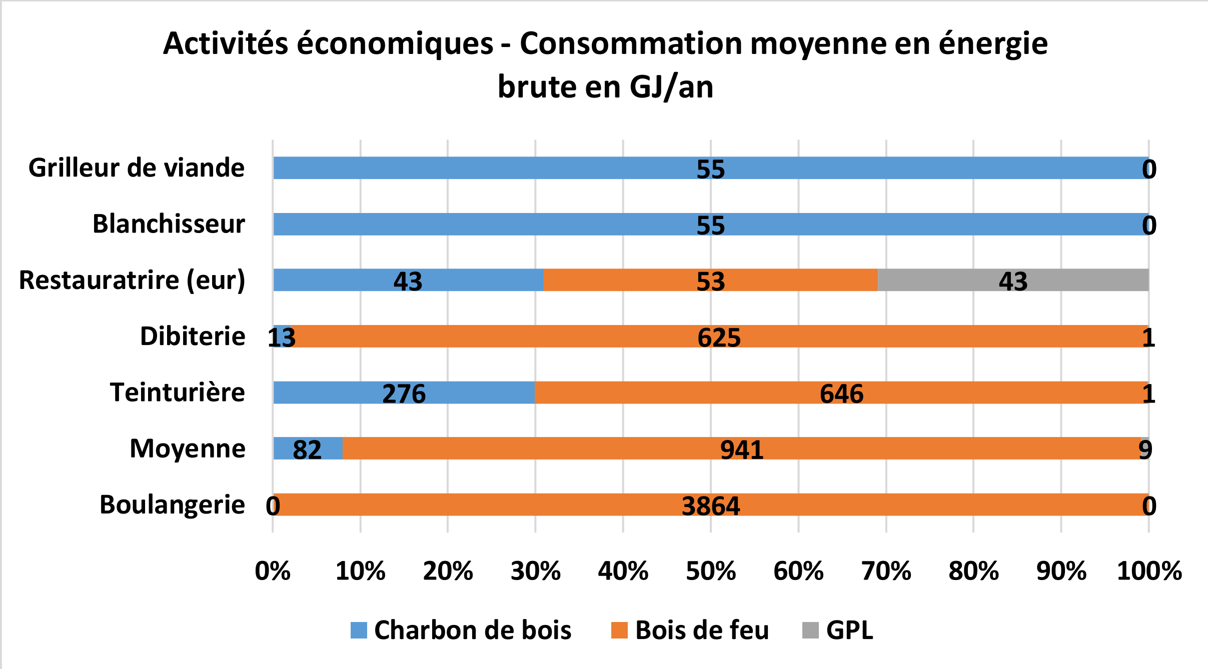


Figure 21: Economic Activities - Average Gross Energy Consumption in GJ/Year

3.7.1.2 Biomass resources available to power the sector

The most promising residues in terms of energy recovery in and around Bamako district appear to be coal dust and shea cakes. Indeed, up to 20% of the total weight of a bag of charcoal, fairly large deposits of fine and coarse dust could be collected in the outlets mainly from charcoal distributors especially retailers operating pre-sale sorting and, to a lesser extent, from end consumers buying by bag. , especially relatively well-off households or professionals such as restaurateurs, dyers. There is already an initiative in place to develop this coal-fired briquettes in Bamako city.

On the shea side, the MaliShi plant, the country's largest butter shea industrial processing unit, located in Banankoro, southeast of Bamako, would have a surplus of biomass to be valued. To produce shea butter, the plant is processing 16,000 tonnes of shea almonds this year. About half (8,000 tons) remain of shea meal, waste, some of which is consumed internally by their boiler. Eventually, the plant will process 30,000 tons of almonds annually, generating 14,000 to 15,000 tons of meal. It is planned to consume a maximum of 6,000 tonnes of meal in the boiler room. 8,000 to 9,000 tonnes of meal can therefore be potentially converted for bioenergy.

The proposed bioenergy pilot project covers the residential but also commercial sector and is entitled: **"Production of biofuels from shea cakes in the Bamako domestic fuel supply basin"**

The aim will be to recover shea cakes from the processing of shea almonds for the production of briquettes and meal buchettes in order to replace a share of wood consumption in the residential and commercial sectors.

3.7.1.3 Challenges to the sector's economic development

The MaliShi factory is interested in making briquettes with its excess shea cake, and distributing them to their shea almond suppliers. Shea nut producers are women who collect and process nuts to extract almonds. Some of the almond suppliers are located in the Bamako supply basin, but others come from more distant areas although a consumption profile similar to the one described above (section 1.2) can be deduced. The process of processing nuts after harvest requested by the industrialist (scalding nuts) requires fuel (firewood). Women in rural areas go to look for wood, which is mostly free of charge. But it has an environmental cost because it is a source of deforestation, as shown in 1.1 above, in addition to cost of time and effort to go and get wood. The industrialist, concerned about the conditions under which his raw material is produced, would like to become an actor in mitigating these impacts.3.6.73.6.6 above

The proposed solution is to provide meal briquettes to these collectors. In doing so, MaliShi would contribute to the sustainability of the value chain, in addition to retaining the farmers' organizations that supply the company with shea almonds.
Other players who would benefit from this product are urban consumers, especially those who have a high consumption of wood. This will give bakers access to a fuel that is affordable in terms of cost, able to substitute all of their wood consumption. This will reduce the pressure on the country's forests.

3.6.8. Description of technology

The production of coal briquettes of dust and shea cake is done in a press. The raw materials here for the production of briquettes are shea meal from the MaliShi factory, and possibly a binder that will guarantee the integrity of the briquette. Before making briquettes, a mixture of raw material and binder should be made and moistened a little. The yield will be 100% of the shea cake. The MaliShi plant says it wants to house the briquettes manufacturing unit, which facilitates logistics for the supply of raw materials.

The process briquette manufacturing process is as follows:

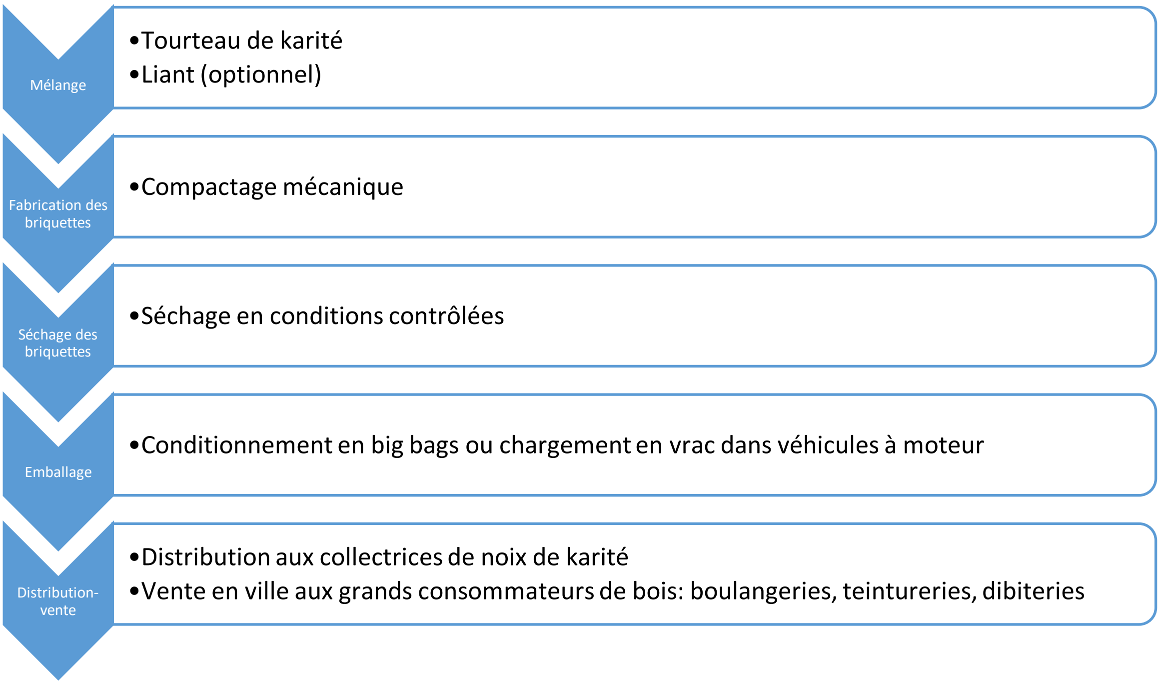


Figure 22: Briquette manufacturing process

Figure 23: Motorized screw press for shea cake briquette

The figure opposite shows the briquettes press developed by Nitidae to compact the shea cake.

The model can be adapted to increase capacity and facilitate automatic conveyor feeding. The pulsation of the briquettes through the endless screw can provide greater pressure and intensity during production. The briquette produced is of high quality and so strong that it does not break easily. Also, it is easy to turn on for combustion and lasts longer when burned.

3.7.1.4 Pre-care of biomass upstream to be valued

As much as the cakes come from a press like Mali Shi, no upstream treatment is necessary. The biomass is quite dry and the powdered format is easy to feed.

The meal deposit at the Mali Shi plant is large enough to run an entire production unit without resorting to other meal deposits, for example, from plants of the same type, or traditional processors on a smaller scale.

3.7.1.5 Description of the final energy product

Shea meal briquettes are good, non-carbonated fuels (18-20 MJ/kg PCI). These briquettes are produced in cylindrical form (see figure below), with the possibility of adapting diameters to consumer requirements (e.g., larger diameter logs for bakeries and other large-scale economic activities).

Figure 24: Photo of briquettes drying on slab and on clast in the sun

3.7.1.6 Consumer Description

In Bamako, 85% of housewives in Bamako prepare 3 meals, the remaining 15% prepare 2 meals. In the village, the rule of preparing three meals a day. For rural areas it should be noted that 98% of the households surveyed heat the water for the toilet, and this almost all year round. Similarly, most households report having an economic activity that uses mainly firewood. The consumption profiles of these actors have been described in 1.2 above.3.6.7 above

The briquettes are intended for households and income-generating activities (bakery, dyer,...) in the capital, although households will be able to access the product through the outlets if they wish. Outside the city, most of the briquettes will simply be distributed to shea nut collectors. The sale of wood to other economic players, such as bakeries in rural areas and small towns, is also possible.

In rural areas, 5% of households buy wood while 98% buy it by collection. The resource is therefore free in these cases. In urban areas in Bamako but also in the surrounding small towns, wood becomes a pay for households and economic activities.

On this basis, the project would take two different approaches depending on the consumer profile: briquettes for shea nut collectors would not be sold but distributed to the farmers' organizations of which they are part, as it would be difficult to find market opportunities in this. However, the industrialist would find an economic interest if in this process he manages to have a premium in the selling price of his shea butter. Since the company has implemented initiatives aimed at reducing the environmental impact of its supply chain, it is showing its environmental commitment and will be able to seek a higher price for their product, through certifications, labels or premiums for environmental quality. This arrangement could become an example in the sub-region, as many butter mining plants are emerging, due to increased international demand and the relocation of industrial activities to shea's countries of origin.

For bricks and logs for consumers in urban areas, the product will be delivered to strategically placed depots and sales outlets to serve as many customers as big as wood consumers; with the possibility of contracting with them and making the delivery on their site. The product, similar to wood, does not need any packaging, so it would be delivered in bulk.

The MaliShi site, located just 22km from Bamako is quite central in the wood-energy supply radius of Bamako (which reaches 150km) and the charcoal sales outlets in the city of Bamako, making distribution possible and advantageous in the capital district.

Consumer buy-in to this new form of domestic energy is crucial for the project. The strategic choice of targeting of economically active consumers is motivated for their greater sensitivity to firewood prices, compared to the non-productive use of fuel. Indeed, the cost of wood, in terms of purchase price but also supply time, logistics, etc. has a direct impact on the cost of their product, and therefore their income. On average, these economic players are more open to adopting new forms of fuel if they find benefits in terms of efficiency and cost. Moreover, since for the most part these activities do not have to do with cooking food, the chances of the product being accepted are increased because there is no risk of "changing the taste of food", which is often the main fear of domestic consumers.

For the specific case of shea nut collectors, their adherence to the project is at the same time an issue for the industrial company committed to the sale of shea almonds, treated with ecological fuel. It will then be necessary to carry out awareness campaigns and pilot phases with some reference farmers' or cooperative organisations, in order to find the best formula to facilitate access to fuel to collectors, and at the same time ensure that the briquettes are well used in the cooking of nuts and will therefore have the impact on the carbon footprint of the shea butter product that is *ultimately* sought after. A complementarity through training in the manufacture of improved homes in banco, economic and adapted to this activity, is to be considered to strengthen the intervention of fuel change. Similarly, an incentive/premium system can be put in place to encourage collectors to join the process.

3.6.9. Conclusion and recommendations

3.7.1.7 Improved technology

In combination with the bricking of shea meal, the promotion of improved fireplaces and the awareness of the ecological impacts of their activity are points of reinforcement of the action of the project.

In rural areas, the rule remains the traditional three-stone home (in 91% of households outside Bamako consulted by the FONABES project). However, the improved version with a banco cap is fairly well developed (52%). In addition, 28% of rural households surveyed say they have a modern, improved home. According to the SDACD, the average efficiency of cooking in rural areas is 18.6%; however, nut scalding operations are often carried out outside the most widely used households, as these are large quantities of material to be treated, and poorer efficiencies can be expected for these cooking operations. The room for improvement would be even greater. The efficiencies of banco households can reach around 30%, and the advantage is that they can be achieved entirely by women themselves, thus having an almost zero impact on the cost and contributing to their perevoir. This action could eventually be held with traditional dyers in Bamako, or bakers and dibitiers who do not use optimized ovens.

3.7.1.8 Recommendations at the political, regulatory, environmental, gender level

As outlined in previous documents, in a country exposed to climate change and where degradation of land and natural resources is a real problem, the wood-energy resource as currently exploited cannot adequately address growing energy needs. The residues of the wood-energy supply chain are minimal, and only the coal dust could be identified in 2.1 as a potentially interesting material for its recovery and use of fuel. Other avenues for improving the efficiency of the sector would be, according to the various policy documents: increasing the supply of wood-energy from planned production and agroforestry; Promote wood-saving through the generalization of improved homes; the structuring and professionalization of the sector and especially special attention to the increase in carbonization yields by improved techniques. The promotion of LPG as a substitute or complement to wood-energy is also envisaged in the documents cited (FONABES, 2017).

As a pilot project, the action will be complemented by insitut capacitybuildingactivities, so that administration officials become aware of the appropriateness and relevance of the project, and with a view to creating mechanisms for measurement, verification and certification that can be replicated in the country.

The project will participate in three areas among the eight lines of action proposed by the Bamako Domestic Fuels Management Scheme in 2017, namely:

- Axis IV: Promoting wood savings
- Axis VI: Supporting the Role of Women in Energy Savings
  Axis VIII: Develop accompanying measures (accompanying, regulation, standardisation, certification

4 Conclusion and Recommendation

The main reason for selecting the seven countries is to focus on projects which have potential for sustainability, that is, steady supply of biomass residue from logging operations and industry with various means of conversion, as well as agroforestry woody species such as shea butter and cashew nuts. The next phase of the project, which commences with output 3.3 report all the way to output 6, is to identify suitable pilot projects in the most appropriate country location bearing in mind the social, economic, political and environmental aspects of the project. Conversion technology will focus on two pathways that currently have the most important applications at the African level: direct combustion and conversion to biogas. This report has given a summary of the most appropriate conversion technologies, including pre-treatments and treatments of biomass residue for conversion to final energy. The focus has been on sectors identified in seven selected countries out of the fifteen countries. The seven different countries, which largely represent the situation of other sub-Saharan African and the conversion technology are shown in the table below.

Table 5: Key forest biomass and key conversion process in participating countries

Country	Major forest waste/agroforestry biomass waste of interest	Main conversion process
1. Cameroon	Wood residue	Direct Combustion
2. Congo	Wood residue	Direct Combustion
3. Democratic Republic of Congo	Wood residue	Direct Combustion
4. Burundi	Wood residue	Direct Combustion
5. Ivory Coast	Cocoa pods	Production de biogas
6. Burkina Faso	Cashew shells or shea butter	Direct Combustion
7. Mali	Shea butter	Production du biogas

5 References

Ackom, E. K., Alemagi, D., Ackom, N. B., Minang, P. A., & Tchoundjeu, Z. (2013). Modern bioenergy from agricultural and forestry residues in Cameroon: Potential, challenges and the way forward. *Energy Policy, 63*, 101-113. doi:10.1016/j.enpol.2013.09.006

AEEP. (2012). *The First Stakeholder Forum of the Africa-EU Energy Partnership*. Retrieved 11 30, 2020, from Africa-EU Energy Partnership (AEEP): http://www.aeep-forum.org/en/archive/2012

AFREC. (2019). *Africa energy balances.*

Branca, G., Cacchiarelli, L., Cardona, C. A., ErikaFelix, Gianvenuti, A., Kojakovic, A., . . . Tolli, M. (2014). *Bioenergy and Food Security Rapid Assessment (BEFS RA) Gasification.* Food and Agriculture Organization of the United Nations (FAO). Retrieved from https://docplayer.fr/9329646-Bioenergie-et-securite-alimentaire-evaluation-rapide-befs-ra-manuel-d-utilisation-gazeification.html

Cameron, L., Mozaffarian, H., & Falzon, J. (2014). *Biomass Waste-to-Energy Toolkit for Development Practitioners.* Energy Research Centre of the Netherlands (ECN). Retrieved from http://www.ecowrex.org/sites/default/files/documents/news/bioenergy_lr.pdf

Champion, W. M., & Grieshop, A. P. (2019). Pellet-Fed Gasifier Stoves Approach Gas-Stove Like Performance during in-Home Use in Rwanda. *Environmental Science & Technology*, 6570-6579. doi:10.1021/acs.est.9b00009

Chyou, Y.-P., Chang, D.-M., Chen, P.-C., Chien, H.-Y., Wu, K.-T., & Chein, R.-Y. (2020). Development of Biomass Gasification Technology with Fluidized-Bed Reactors for Enhancing Hydrogen Generation: Part I, Hydrodynamic Characterization of Dual Fluidized-Bed Gasifiers. *Applied Sciences, 10*(2), 1-18. doi:10.3390/app10010002

Clean Cooking Catalog. (2020). (United Nations Foundation) Retrieved 11 27, 2020, from Clean Cooking Catalog: http://catalog.cleancookstoves.org/stoves/434

Comité Interprofessionnel de l'Anacarde du Burkina. (2018). *Opportunités d'investissement dans le secteur agricole au Burkina Faso :cas de la filière anacarde.* Retrieved from https://www.pndes2020.com/pdf/Intervention%20Fili%C3%A8re%20Anarcarde.pdf: https://www.pndes2020.com/pdf/Intervention%20Fili%C3%A8re%20Anarcarde.pdf

Constantine, T., Aymard, S. Q., Donald, Z. K., Patrick, O. R., & Jean-Claude, Y. (n.d). *DESS ENERGIE: Energy Boulevard of Congo.* Retrieved from https://www.hec.ca/formations-internationales/dess-congo/cohorte-1/DESS_CONGO_Strategie_rapport.pdf

DEFRA. (2011). *Anaerobic Digestion Strategy and Action Plan: A commitment to increasing energy from waste through anaerobic digestion.* London: Department for Environment, Food and Rural Affairs (DEFRA). Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69400/anaerobic-digestion-strat-action-plan.pdf

E4Tech. (2009). *Review of Technologies for Gasification of Biomass and Wastes.* Final Report, National Non-Food Crops Centre (NNFC). Retrieved from https://www.e4tech.com/uploads/files/NNFCC_final_report_E4tech_090609.pdf

Esseqqat, H. (2011). *Renewable Energies in the Democratic Republic of Congo.* Retrieved from https://postconflict.unep.ch/publications/UNEP_DRC_renewable_energy_FR.pdf

EUEI. (2014). *Cameroon: National Energy Efficiency Policy, Strategy and Action Plan in the Electricity Sector.* EU Energy Initiative. Retrieved from http://www.euei-pdf.org/sites/default/files/field_publication_file/140605_euei_factfile_cameroon_rz_01_web.pdf

FONABES. (2017). *Schéma Directeur d'Approvisionnement en Combustibles Domestiques de Bamako.*

Global Petrol Prices. (2020, 03). Retrieved from Electricity prices: https://www.globalpetrolprices.com/electricity_prices/

Government of Burkina Faso. (2017). LAW N ° 014-2017 / AN: General Regulations of the Energy Sector. Retrieved from https://lavoixdujuristebf.files.wordpress.com/2018/02/loi_014-2017_portant_reglementation_gle_du_secteur_de_l_electricite.pdf

Guidal, A., Herail, A., & Rosenstock, T. S. (2018). *The case for investment in industrial charcoal production in the Republic of Congo: Results of a technical and economic feasibility assessment of Congo Carbo Industrie.* International Centre for Research in Agroforestry (ICRAF). Retrieved from https://www.ctc-n.org/system/files/dossier/3b/charcoal_brief_en_final_012019.pdf

Herail, A., & Guidal, A. (2018). *Feasibility of industrial charcoal production in the Republic of Congo: An assessment of Congo Carbo Industrie.* Kinshasha: World Agroforestry Centre. Retrieved from https://www.ctc-n.org/system/files/dossier/3b/en-final_cci.pdf

Holubcik, M., & Nosek, R. J. (2012). Optimization of the Production Process of Wood Pellets by Adding Additives. *International Journal of Energy Optimization and Engineering, 1*(2), 20-40. doi:10.4018/ijeoe.2012040102

IEA. (2009). *IEA Bioenergy Annual Report 2009.* (J. Tustin, Ed.) Retrieved from https://www.ieabioenergy.com/wp-content/uploads/2013/10/IEA-Bioenergy-2009-Annual-Report.pdf

IFC. (2017). *Converting Biomass to Energy.*

Inyenyeri. (2020). Retrieved 11 27, 2020, from Inyenyeri: https://www.inyenyeri.com/

Jimenez, A. C., & Lawand, T. (2000). *Renewable Energy for Rural Schools.* National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/docs/fy01osti/26222.pdf

Johnson, O. W., Han, J. Y.-C., Knight, A.-L., Mortensen, S., Aung, M. T., Boyland, M., & Resurrección, B. P. (2020). *Assessing the gender and social equity dimensions of energy transitions.* Stockholm Environment Institute (SEI). Retrieved from https://www.sei.org/wp-content/uploads/2020/04/assessing-the-gender-and-social-equity-dimensions-of-energy-transitions-2020.pdf

Kabemba, C. (2005). Democratic republic of Congo. *South African Journal of International Affairs*, 43-60. doi:10.1080/10220460509556748

Kusakana, K. (2016). *A Review of Energy in the Democratic Republic of Congo.* Retrieved from https://www.researchgate.net/publication/306380971_A_Review_of_Energy_in_the_Democratic_Republic_of_Congo

LACQ. (n.d). *Biomass Cogeneration Plant.* Non-Technical Summary. Retrieved from https://www.eib.org/attachments/registers/52734857.pdf

Le Monde. (2020, 10 02). *In Ivory Coast, sharp rise in the price of cocoa before the presidential election*. Retrieved 11 26, 2020, from Le Monde: https://www.lemonde.fr/afrique/article/2020/10/02/en-cote-d-ivoire-forte-hausse-du-prix-du-cacao-avant-la-presidentielle_6054484_3212.html

MAF. (2019, 11 22). *Ivory Coast: agricultural context and international relations*. Retrieved 11 26, 2020, from Ministry of Agriculture and Food: https://agriculture.gouv.fr/cote-divoire-contexte-agricole-et-relations-internationales

MEI. (n.d.). *Industries by sector*. Retrieved 11 26, 2020, from Ministry of Economy and Industry (MEI): https://economie.gouv.cg/fr/activit%C3%A9s-industrielles-par-fili%C3%A8re

Mohideen, R. (2018). *Energy Technology Innovation in South Asia: Implications for Gender Equality and Social Inclusion.* Mandaluyong City: Asian Development Bank. Retrieved from https://digitalcommons.ilr.cornell.edu/cgi/viewcontent.cgi?article=1667&context=intl

PNUD. (2013). *Étude NAMA sur le charbon de bois durable en Côte d'ivoire.*

Prevot, G. (2010). *Energy Recovery from Waste from Biomass of Plant Origin.* ENVALYS. Retrieved from https://www.record-net.org/storage/etudes/08-0231-1A/rapport/Rapport_record08-0231_1A.pdf

R.Aouaké, D.Gomeu, A.Guhur, & R.Vaudry. (2019). *Diagnostic bioénergies de la région de la Mé.* Nitidae.

Republic of Congo. (2017). *Preparation of the National Plan 2017 - 2021: Strategic Framework Development.* Retrieved from http://extwprlegs1.fao.org/docs/pdf/Con184010.pdf

SE4All. (2020). *Burundi*. Retrieved 11 27, 2020, from Sustainable Energy for All: Africa Hub: https://www.se4all-africa.org/seforall-in-africa/country-data/burundi/

Sharma, S., Meena, R., Sharma, A., & Goyal, P. (2014). Biomass Conversion Technologies for Renewable Energy and Fuels: A Review Note. *Journal of Mechanical and Civil Engineering*, 28-35. doi:10.9790/1684-11232835

Soderling, L. (1999). *Structural Policies for the International Competitiveness in Manufacturing: The Case of Cameroon.* Organisation for Economic Co-Operation and Development. Retrieved from https://dx.doi.org/10.2139/ssrn.191148

Somcharoenwattana, W., Menke, C., Kamolpus, D., & Gvozdenac, D. (2011). Study of operational parameters improvement of natural-gas cogeneration plant in public buildings in Thailand. *Lancet, 43*, 925-934. Retrieved from 10.1016/j.enbuild.2010.12.016

Thomas, T. T., Alexis, K., & Salomon, D. B. (2010). Electricity Self-Generation Costs for Industrial Companies in Cameroon. *Energies, 3*, 1353-1368;. doi:10.3390/en3071353

UNIDO. (2005). *Industrial Performance and Capabilities of Cameroon: Analysis of the Industrial Sector.* United Nations Industrial Development Organization (UNIDO). Retrieved from https://www.unido.org/sites/default/files/2009-04/Industrial_performance_and_capabilities_of_cameroon_0.pdf

Wathore, R., Mortimer, K., & Grieshop, A. (2017). In-Use Emissions and Estimated Impacts of Traditional, Natural- and Forced-Draft Cookstoves in Rural Malawi. *Environmental Science & Technology, 51*, 1929-1938. doi:10.1021/acs.est.6b05557

WFP. (2016). *Safe Access to Fuel and Energy in Burundi: An appraisal report.* World Food Programme. Retrieved from https://docs.wfp.org/api/documents/WFP-0000019952/download/

World Bank. (2014). *Clean and Improved Cooking in Sub-Saharan Africa : A Landscape Report.* Washington DC.: World Bank Group. Retrieved from World Bank. https://openknowledge.worldbank.org/handle/10986/22521

World Bank. (2015). *Republic of Cameroon: Fostering Skills for Inclusive Workforce Development, Competitiveness and Growth.* World Bank Group. Retrieved from http://documents1.worldbank.org/curated/pt/372101468019812053/pdf/Cameroon-SDGC-A-Framework-for-Action-vEnglish-April-2015.pdf

World Bank. (2018). *Democratic Republic of Congo Systematic Country Diagnostic : Policy Priorities for Poverty Reduction and Shared Prosperity in a Post-Conflict Country and Fragile State.* World Bank Group. Retrieved from http://hdl.handle.net/10986/30057

World Bank. (2019). *Burundi Offgrid Access Project.* World Bank Group. Retrieved from http://documents1.worldbank.org/curated/en/729191565283179350/pdf/Concept-Project-Information-Document-PID-Burundi-Access-to-Sustainable-Energy-P164435.pdf