



Food and Agriculture Organization
of the United Nations

Off-grid rural electrification options using crop and woody residues in Côte d'Ivoire

 Bioenergy and Food Security
(BEFS) case study

Purpose of the BEFS Case studies

The overall objective of these case studies is to present a range of bioenergy supply chains and look at how to assess the potential within the chains based on the BEFS Approach and BEFS RA tools. The case studies have been developed for training purposes, to illustrate the BEFS approach and tools and how they are applied. They present examples of bioenergy supply chains found in countries where BEFS has supported national stakeholders.

Acknowledgements

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Case study focus

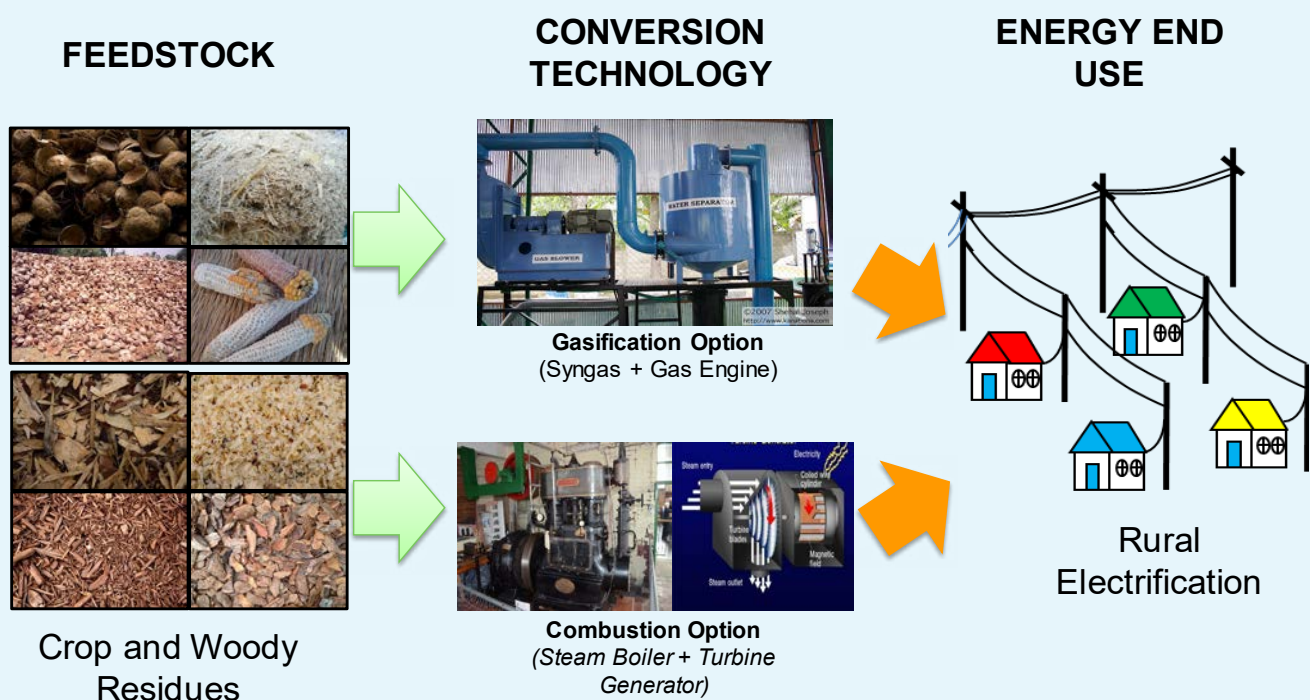
Around two-thirds of the population currently have access to some form of electricity in Côte d'Ivoire, but this share reduces to one in three households in rural areas. The Government of the country is interested in understanding which bioenergy supply chains could be viable for the production of electricity from off grid solutions in rural areas. The case study illustrates the steps required to determine if a series of biomass based value chains can be established to produce electricity in rural areas. The biomass chains considered in this case study are those of crop

and woody residues for the generation of electricity through combustion and gasification technology. The case study begins with setting out current policies and the country context, and then analyses the availability of biomass. Once the biomass available is estimated, a techno-economic analysis of electricity from gasification and combustions of these residues is carried out. These technologies are compared to the standard off grid option of diesel powered generators.

Key elements of the bioenergy supply chain

Feedstock	Technology	Energy end use option	BEFS RA Tools
crop residues, forestry harvesting residues and wood processing residues	combustion and gasification	rural electrification	crop residues tool, woodfuel tool, combustion tool and gasification tool

The case study's bioenergy supply chain



Glossary

Biodiesel

Biodiesel is called the mixture of esters obtained from the transesterification of triglycerides contained in oleo chemical feedstock such as vegetable oils, tallow and greases. Biodiesel can be used as substitute of diesel fuel.

Bioenergy

Bioenergy is the energy generated from the conversion of solid, liquid and gaseous products derived from biomass.

Biogas

Biogas is a mixture of gases, mainly composed by methane (50-60 percent) obtained from the anaerobic digestion of biomass. In general, most of the organic wastes can be digested (excepting lignin). Among the most common biogas substrates can be counter livestock residues, municipal solid wastes (MSW), water treatment plants sludges.

Biomass

Biomass is any organic matter, i.e. biological material, available on a renewable basis. Includes feedstock derived from animals or plants, such as wood and agricultural crops, and organic waste from municipal and industrial sources.

Biomass assessment

Biomass assessment analysis the production, availability and accessibility of biomass feedstock for energy production. The assessment considers all uses of the potential feedstock, such as their use in maintaining soil fertility, or as feed for livestock before calculating the amount of biomass available for bioenergy production. This is essential to avoid any adverse impact that bioenergy production may have on agricultural sustainability. The result of the assessment is the identification of the main types of biomass feedstock available for bioenergy production as well as their geographical distribution within a specific region or country.

Briquettes and pellets

Solid biofuel obtained by compressing biomass in order to increase density. The primary difference between briquettes and pellets is shape and size. Briquettes are generally bigger than pellets.

Charcoal

A porous black solid obtained from biomass. It is an amorphous form of carbon obtained by the thermal decomposition of wood or other organic matter in the absence of air.

CHP

CHP stands for the cogeneration of heat and power. It is an efficient method for the simultaneous generation of at least two energy forms, including heat, power, and/or cooling.

Combustion

Combustion is the most common way of converting solid biomass fuel to energy. Around 90% of the energy generated from biomass is obtained through combustion, which is traditionally used for heating and cooking. Moreover, biomass combustion technologies are actively used for electricity generation at rural and industrial scales by means of steam.

Crop residues

Plant material remaining after harvesting, including leaves, stalks, roots etc.

Ethanol

Ethanol is a short chain alcohol, which can be directly used as fuel or blended with gasoline. It can be produced through the fermentation of glucose derived from sugar-bearing plants (e.g. sugar-cane), starchy materials after hydrolysis or lignocellulosic materials (e.g. crop residues, Miscanthus) after pretreatment and hydrolysis.

Forest harvesting residues

Forest harvesting residues are parts of felled trees which are not removed from the forest. The rate of removal varies among forests and usually depends on the end product that will be made and the cost-effectiveness of removing the tree. In the case of industrial roundwood, upper logs, branches and different cut-offs are often left in the forest, while stems are removed. Sometimes, stems are debarked in the forest.

Gasification

Gasification is thermochemical process where biomass is transformed into a gas called syngas. This gas is a mixture mostly composed by hydrogen, methane, and nitrogen. Depending on processing technology, conditions and gasifying agent (i.e. air, oxygen or water). The syngas has different composition and as result different fuel qualities.

Livestock residues

Residues originating from livestock keeping. It mainly includes solid excreta of animals.

Roundwood

Wood in the rough. Wood in its natural state as felled, or otherwise harvested, with or without bark, round, split, roughly squared or other forms (e.g. roots, stumps, burls, etc.). It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period - calendar year or forest year.

Sawnwood

Sawnwood, unplanned, planed, grooved, tongued, etc., sawn lengthwise, or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboards, "lumber", sleepers, etc.) and planed wood which may also be finger jointed, tongued or grooved, chamfered, rabbeted, V-jointed, beaded, etc. Wood flooring is excluded.

Techno-economic assessment

In the bioenergy context, Techno-economic (TE) assessment facilitates a data-driven decision making about the performance of a bioenergy value chain, in a given context. This methodology is based on understanding the technical (e.g., technology feasibility, biomass supplying) and economic (e.g., production costs, profitability, capital investments) features of these value chains. Depending on the context and objectives, TE assessments can be extended to include socio-economic and environmental aspects.

Wood processing residues

These residues include sawdust, slabs and chips generated as residues during the wood processing. The amount of residues generated in a sawmill depends on the type of technology used and its efficiency. Often, these residues are not fully utilized due to the lack of demand in the immediate vicinity of the processing plant.

Woodfuel

Woodfuels arise from multiple sources including forests, other wooded land and trees outside forests, co-products from wood processing, post-consumer recovered wood and processed wood-based fuels.

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Policy background and introduction

Access to electricity has reached two-thirds of the population in Côte d'Ivoire, although the share of the population in rural areas that has access to electricity is less. In rural areas, one household in every three is connected to the grid or has some means of generating electricity.

Côte d'Ivoire has a Strategic Development Plan (2011-2030) that aims to increase access to sustainable energy through the development of new renewable energy sources for rural communities. Aligned with this, the Master Plan for Electricity Transmission and Production (2014-2030) aims to ensure that at least 80 percent of the population have access to electricity by 2020. With around 3.7 million people living in rural communities with little or no access to electricity, the government has prioritized the promotion of decentralized electricity generation solutions, including systems that use renewable and locally available resources such as biomass. Decentralised energy systems and modern bioenergy technologies are considered to represent a possible option for the provision of electricity in rural areas (Le Ministère des Mines du Pétrole et de l'Énergie, 2014).

Bioenergy and food security (BEFS) approach

The Bioenergy and Food Security (BEFS) Approach has been developed by FAO to support countries to develop evidence based sustainable bioenergy policies. The approach supports countries in understanding the linkages between food security, agriculture and energy, and building sustainable bioenergy policies and strategies that foster both food and energy security and contribute to agricultural and rural development. A core element of the BEFS Approach is the BEFS sustainable bioenergy assessment component. The assessment covers the whole bioenergy pathway starting from feedstock availability assessment to analysis of energy end use options. The first step in the assessment component is the BEFS Rapid Appraisal (BEFS RA). The BEFS RA consists of a set of excel based tools which provide an initial indication of the sustainable bioenergy potential and of the associated trade-offs. The BEFS RA is divided into three major components: Country Status, Biomass Assessment (Natural Resources) and Energy End Use Options (Techno-economic Analysis). Each major component has one or more excel based tools linked to it.

The steps of the BEFS RA analysis:

Step 1: Country Status

This step collects information on the country status and defines the context, needs and constraints in the key sectors such as agriculture, food security, energy and the environment.

Step 2: Natural Resources: Biomass Potential Assessment

The biomass assessment estimates feedstock availability, considering competing uses and needs. The output is an initial indication of the quantities of feedstock available from crop and livestock residues, forest harvesting and wood processing residues, as well as the potential availability of crops for energy production. Profitability of different crops is also taken into consideration.

Step 3: Energy End Use Options: Techno-economic Analysis

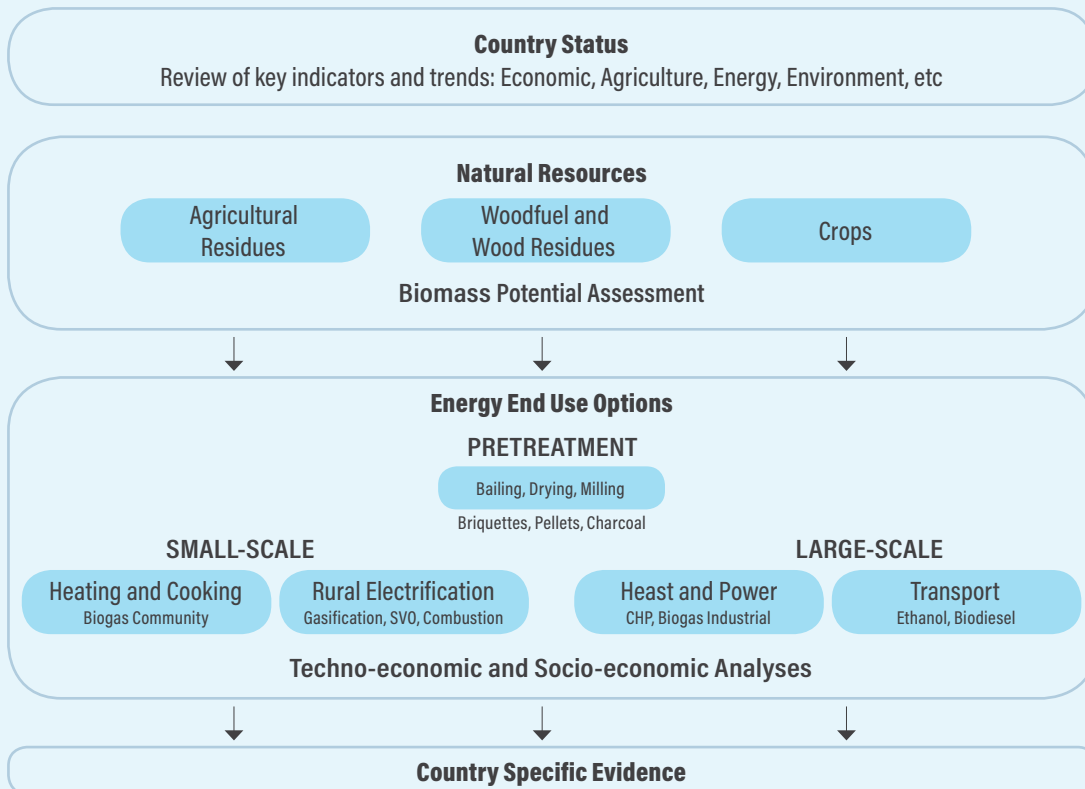
The energy end use options module evaluates the following bioenergy options:

- ▶ Intermediate or final products: briquettes, pellets and charcoal;
- ▶ Heating and cooking: biogas community;
- ▶ Rural electrification: gasification, straight vegetable oil (SVO) and combustion;
- ▶ Heat and power: combined heat and power (CHP) and industrial biogas; and
- ▶ Transport: ethanol (1st Generation, 2nd Generation and Molasses) and biodiesel.

Thus, given the large agriculture and forestry sectors, there might be scope in using crop residues and forestry residues as feedstock for bioenergy production. However, there is concern around both the availability and the sustainability of using these residues for bioenergy production. This case study presents some of the assessment of a selection of value chains for the production of electricity, namely through combustion and gasification of crop and woody residues.¹ The analysis is based on the BEFS Approach and BEFS Rapid Appraisal tools, see box below.

¹ The case study builds on work carried in the field FAO in response to a request for support by the Government of Côte d'Ivoire to carry out an initial assessment of the feasibility of producing electricity in off grid biomass based systems using agriculture and woody residues in rural areas. A working group on bioenergy was set up as part of this process. The working group on bioenergy included representatives of the main government institutions that play a role in the development of the bioenergy sector in Côte d'Ivoire. The group led the process in the country.

Each tool can be used individually but the approach advocates that output from each stage should be used as input into the following steps of the analysis. The tools are excel based and globally applicable. They can be used with limited user defined data and default values are provided. The analysis can be carried out at country or local level and tailored to address the specific needs of countries. In fact, countries can decide to assess a wide spectrum of bioenergy supply chains or, for example, to keep the analysis specific to crop residues for cooking or livestock residues for biogas generation. example.



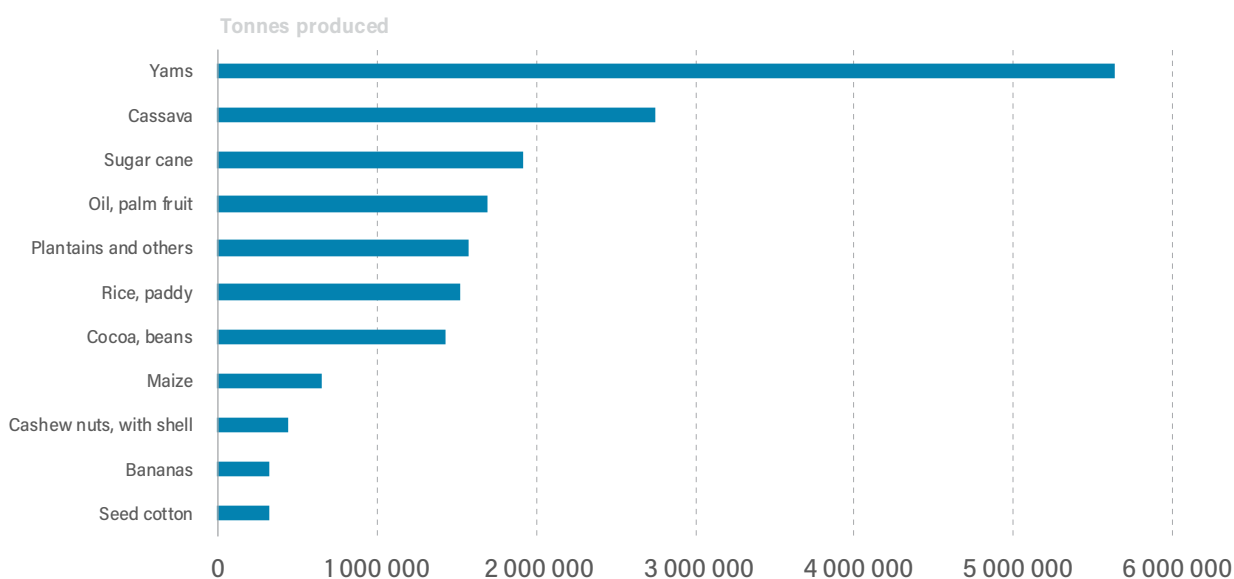
The context: agriculture, forestry, energy policy in Côte D'Ivoire

The Republic of Côte d'Ivoire is a West African country with a population of 24.3 million, of which 44.5 percent was classified as rural in 2017 (Institut National de la Statistique de Côte d'Ivoire, 2014). The country has a relatively high per capita income compared to other countries of the region (USD 1 662 in 2017). Nonetheless, poverty rates have been increasing with 46.3 percent of the population living below the national poverty line and 15.4 percent of the population categorized as undernourished (World Bank, 2015) (UNDP, 2014).

The agriculture sector plays a key role in the national economy. In 2015 it contributed just over 20.5 percent to the country's GDP and in 2017, employed 48.3 percent of the population (FAOSTAT, 2018). Agricultural production is dominated by smallholder farmers with average farm sizes ranging from 1.5 to 5.0 hectares. Existing large-scale production is mainly oriented to export markets. Côte d'Ivoire is a large producer of yams, cassava, sugarcane and palm oil fruit (**Figure 1**) and exports cocoa products, cashew nuts and palm oil (**Figure 2**).

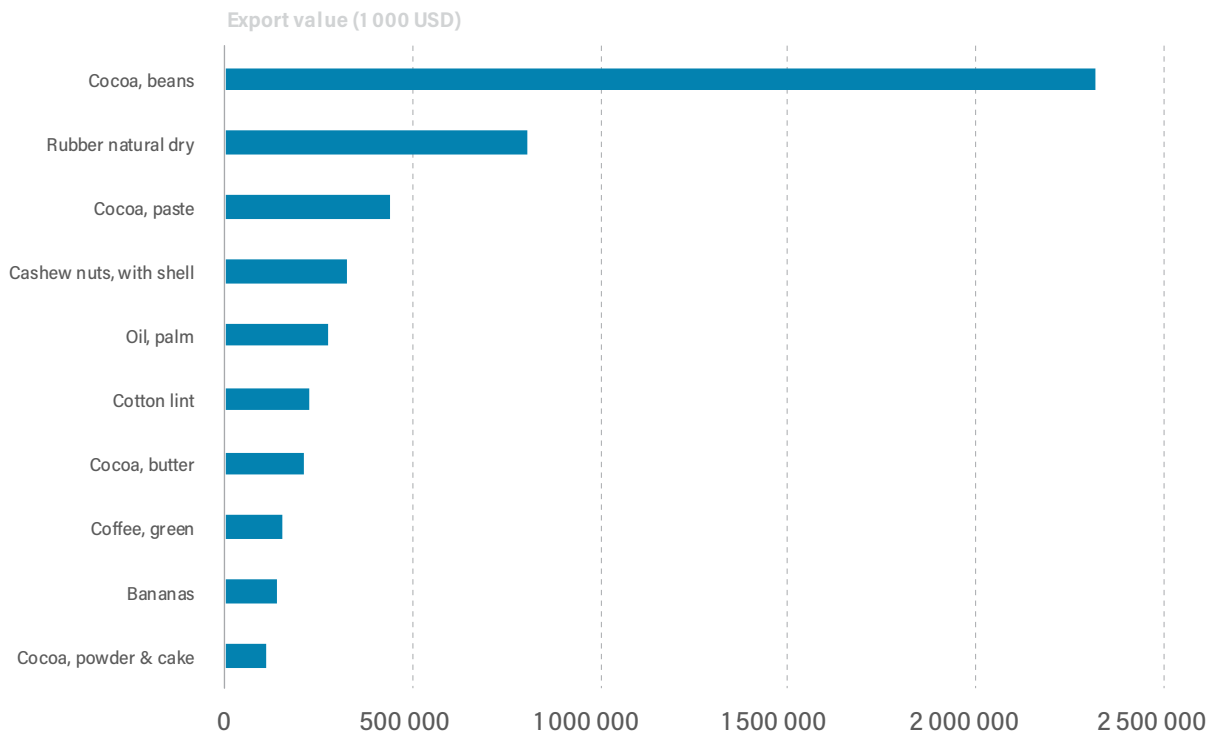
Côte d'Ivoire - Key statistics					
24.3 million population	44.5% of population living in rural areas	1 in 2 living below national poverty line	20.5% agriculture sector share in GDP	1 in 2 employed in agriculture sector	3.7 million rural population with little or no electricity access

FIGURE 1. Main crops produced in Côte d'Ivoire (average 2010 - 2014)



Source: Ministère de l'Agriculture et du Développement Rural, 2014

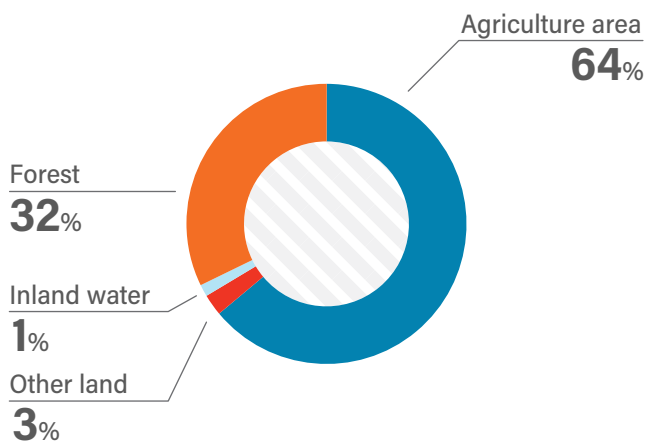
FIGURE 2. Export values for the main agricultural commodities in Côte d'Ivoire



Source: FAO, 2015)

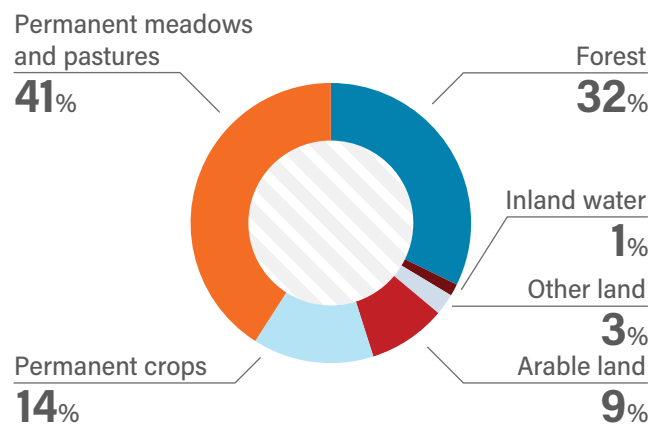
Based on the land use classification of 2013, approximately one third of the country is classified as forest and more than 60 percent as agricultural land (Figure 3). The major part of the agricultural land is covered by permanent meadows, pasture and permanent crops, with approximately 15 percent reported to be arable land (Figure 4).

FIGURE 3. Land use classification in Côte d'Ivoire in 2013



Source: Adapted from (Knomea, 2015)

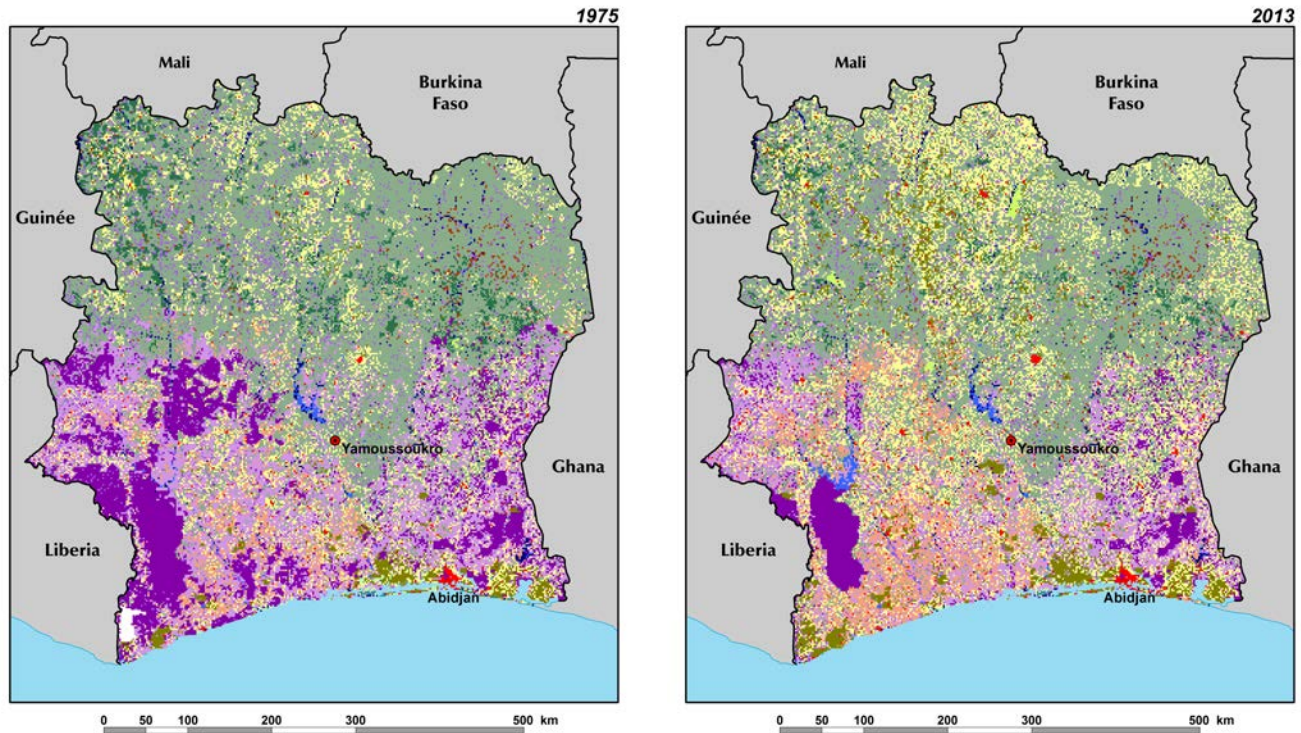
FIGURE 4. Detailed land use classification in Côte d'Ivoire in 2013



Source: Adapted from (Knomea, 2015)

Data on land use and land cover change show a drastic difference in the period from 1975 to 2013. The change was primarily driven by agricultural expansion due to population growth and farming being one of the main employment sectors. Agriculture is spread across the country, except in the northeast, where National Park Comoé is located (**Figure 5**). The most important export crops, such as coffee and cocoa, are produced in the southern half of the country (CILSS, 2016).

FIGURE 5. Land use/land cover change: land cover in 1975 (left), land cover in 2013 (right)



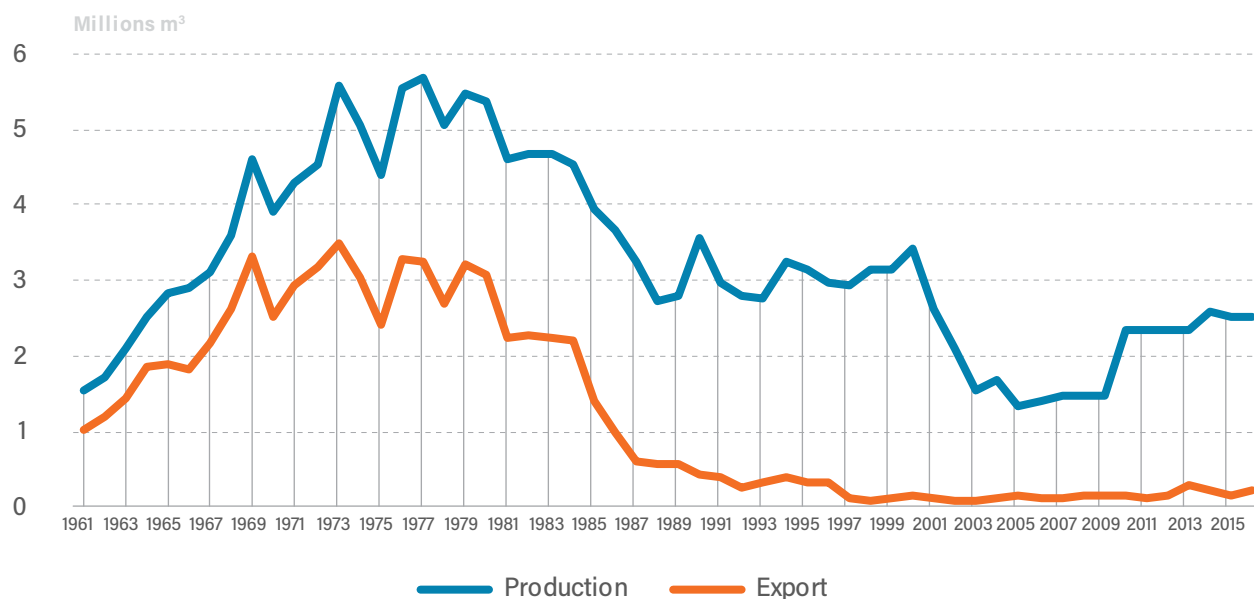
Occupation des Terres / Land Cover

 Forêt / Forest	 Cultures irriguées / Irrigated agriculture
 Forêt dégradée / Degraded forest	 Cultures des bas-fonds et de décrue / Agriculture in shallows and recession
 Forêt galerie & formation ripicole / Gallery forest & riparian forest	 Plantation
 Forêt claire / Woodland	 Habitation / Settlements
 Forêt marécageuse / Swamp forest	 Sols dénudés / Bare soil
 Mangrove	 Terrains rocheux / Rocky land
 Savane / Savanna	 Surfaces sableuses / Sandy area
 Savane herbacée / Herbaceous savanna	 Carrière / Open mine
 Bowé	 Plans d'eau / Water bodies
 Fourré / Thicket	 Prairie marécageuse - vallée inondable / Wetland - floodplain
 Zone de culture / Agriculture	

Source: Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS, 2016)

Since the 1960s, timber production has been an important source of income for Côte d'Ivoire. However, due to unsustainable forest management, forestry resources have been severely depleted. As a result, the volume of standing stocks and industrial roundwood production have significantly declined over the past three decades, see **Figure 6**. By 2013, Côte d'Ivoire had lost nearly 60 percent of the dense tropical forests that existed in 1975, gallery forest decreased by 20 percent compared to 1975, degraded forest decreased by 28 percent and woodland area by 48 percent (CILSS, 2016).² Today, most of the forests are severely degraded or are at an early stage of secondary growth, except for those in well protected areas.

² In terms of area, 60 percent of the 37 300 km² of dense tropical forests that existed in 1975 have been lost and gallery forest decreased from 17 100 km² in 1975 to 14 130 km² in 2013.

FIGURE 6. Industrial roundwood production in and export from Côte d'Ivoire from 1961 to 2015

Source: FAO, 2018

In Côte d'Ivoire, 98.9 percent of forest area is publicly owned and under the responsibility of the Ministry of Water and Forests. The forests are divided into two classes: permanent forest estates (also called *forêts classées*) and the logging perimeters (the so-called *périmètres d'exploitation forestière* – PEFs). The permanent forest estates are under the direct management of SODEFOR (*Société de développement des forêts*), a government corporation tasked with the management of forest reserves and the provision of advisory services. Parts of these forests are protected, and others are managed for timber production. Private companies, which obtained logging concessions issued by the Ministry of Water and Forests (ETTF, 2018) [2], manage the PEFs. It is in these PEFs that most of the timber production takes place.

The forest industry in Côte d'Ivoire is composed of several hundred small processing units and only a few big enterprises. A large part of the industry is foreign-owned. Typically, wood is transported from the regions in which it grows to the port of Abidjan in the east, where the vast bulk of wood-based manufacturing takes place, or to the port of San Pedro in the west. The main products exported from Côte d'Ivoire are flooring, logs from planted forests, mouldings, particle boards, plywood, sawn wood, and veneer.

Despite the recent forest management efforts including reforestation programmes, reformation of logging activities, increasing protected areas, and encouraging private investments in forestry, deforestation trends have so far not been reverted. The expansion of agriculture, driven by an increasing population, remains the key driver of deforestation in Côte d'Ivoire (Ehuitché, 2015).

Energy demand within the country is mostly met by biomass and waste (69 percent), followed by oil products (21 percent), electricity and natural gas (10 percent), as illustrated in **Figure 7**. The largest demand is from the residential sector, where 93 percent is covered by biomass and waste in the form of traditional fuelwood and charcoal for cooking and heating.

FIGURE 7. Energy balance for Côte d'Ivoire

Unit: ktoe	Coal and peat	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Geothermal solar etc.	Biofuels and waste	Electricity	Heat	Total
Total primary energy supply	0	3433	-1352	1651	0	165	0	10110	-75	0	13932
Production		967		1651		165		10110			12893
Import		3370	212								3582
Export		904	1564						75		2543
Final consumption	0	0	1660	255	0	0	0	5334	498	0	7747
Industry			258	255					149		662
Transport			959								959
Residential			190					4779	172		5141
Commercial and public services			98					555	165		818
Agriculture/forestry			105						12		117
Fishing											0
Non-specified											0
Non-energy use			50								50

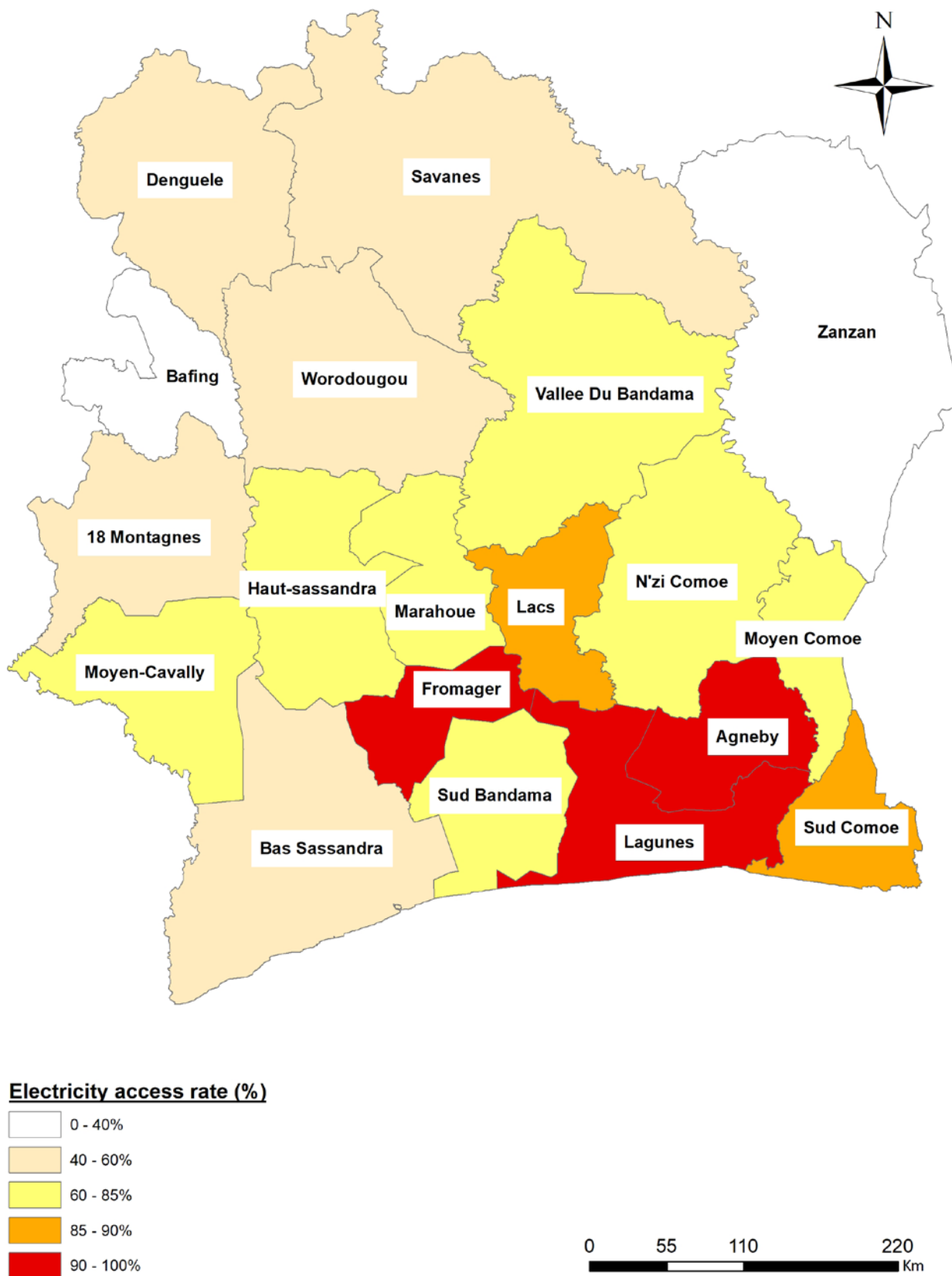
Source: IEA, 2018

According to the World Bank, about 62 percent of the population in Côte d'Ivoire had access to electricity in 2014. However, this coverage decreases to 36.5 percent of the population in rural areas (**Figure 8**). The efforts to increase electricity access in rural areas faces the challenge of expanding the coverage of the national electricity grid and the deployment of decentralized solutions.

Côte d'Ivoire's national electricity grid is mainly concentrated in urban and peri-urban areas. According to the National Development Plan, the grid is affected by inadequate and aging infrastructure. Moreover, the utility company has also confronted serious revenue deficits largely due to erratic repayments from users. These factors, and the distance of many communities and villages from the grid, limit the ability to increase rural electricity coverage through expansion of the existing network (Ministry of Economy and Finance, 2012).

In the case of decentralized electricity generation, the National Regulatory Authority of the Electricity Sector for Côte d'Ivoire (ANARE) reported 55 decentralized diesel power plants in operation in 2015 with a total installed capacity of 5.6 MW and an annual electricity generation of 10 GWh. The operation of this type of plant is associated with high operating costs mainly due to the price and transportation cost of diesel to and from isolated rural areas where these systems are usually located (Autorité Nationale de Régulation du secteur de l'Electricité de Côte d'Ivoire (ANARE), 2015).

FIGURE 8. Electricity access rates by district in Côte d'Ivoire



Source: Grid reinforcement and rural electrification project in Côte d'Ivoire, 2015, adapted from: (Autorité Nationale de Régulation du secteur de l'Electricité de Côte d'Ivoire (ANARE), 2015) and (African Development Bank, 2015)

Biomass assessment

Considering the energy policy objectives and the interest in developing bioenergy supply chains that use available crop residues and forestry residues and the current agriculture and forestry setting, the first step in the analysis is to define how much biomass from crop residues and forestry residues can be considered available.

This step of the analysis identifies the types and amounts of crop and forestry residues that could be used to produce bioenergy. In terms of forestry residues, the residues considered are forest harvesting residues and wood processing residues. The estimated amounts of available biomass are then the basis for the second part of the analysis, namely the techno-economic analysis.

Crop residues

As a first step, crop production in Côte d'Ivoire (see **Table 1** below) is reviewed so as to define the main crops produced. Subsequently, all residue types per crop are listed and screened to define which ones are suitable for electricity production through gasification and combustion technologies.

Table 1 lists the top 20 crops in the country. In terms of production, yams and cassava are the crops with the largest volume of production. These are followed by sugar cane, oil palm, plantains, cocoa and rice. The annual production of each one of these crops exceeds 1 million tonnes. From an area point of view, cocoa, cashew, and yam cover the largest areas of harvested land, followed by coffee and rice.

TABLE 1. Top 20 crops produced in the country ranked by production quantity (average over the range 2010 – 2014)

Crop	Production quantity	Area harvested	Yield
	tonnes	ha	tonnes/ha
1 Yams	5 627 924	862 279	6.53
2 Cassava	2 443 565	418 041	6.59
3 Sugar cane	1 798 000	25 492	70.53
4 Oil, palm fruit	1 637 600	267 142	6.33
5 Plantains and others	1 559 770	421 243	3.76
6 Cocoa, beans	1 357 687	2 642 500	0.54
7 Rice, paddy	1 001 753	615 208	1.64
8 Maize	637 140	321 259	2.01
9 Cashew nuts, with shell	382 000	1 175 531	0.38
10 Bananas	306 686	7 273	43.25
11 Rubber, natural	266 394	164 075	1.62
12 Seed cotton	200 106	300 400	1.11
13 Coconuts	147 409	64 271	2.46
14 Coffee, green	136 059	648 231	0.21
15 Vegetables, fresh nes	134 500	16 349	8.23
16 Okra	122 986	47 017	2.61
17 Pineapples	103 399	2 484	47.90
18 Chillies and peppers, dry	91 791	21 061	4.28
19 Eggplants (aubergines)	88 882	13 106	6.86
20 Groundnuts, with shell	86 012	76 703	11.18

Source: FAOSTAT

Considering overall production, a subset of crops and their related residues were selected. **Table 2** shows the full list of crops, related residues, the location where the crop residues are generated, the residue to crop ratio and the amount of residues generated. Crop residues can be generated in the field or at the processing plant. For example, residues such as straw and stalks are found in the field, while residues such as bagasse and husk are generated in the processing plant. This is an important distinction to make as it has strong implications for feedstock costs. The actual amount of residue generated is then calculated using the residue-to-crop ratio.³ In terms of volumes of residues

³ Ratio between the amount of residue generated and the amount of the crop's main product. See the manual on crop residues for further information and description of the methodology. The full reference is available in the reference section.

generated, as shown in **Table 2**, we find that oil palm fronds, plantain stipe, cocoa bean pods, maize stover and rice straw are the ones being generated in the largest volumes.

TABLE 2. Crops and residue types included in the natural resource assessment for Côte d'Ivoire

Crop	Type of residue	Location of the residue	Residue to crop ratio	Residues produced (tonnes/year)
Cassava	Stalk	Spread in the field	0.13	317 663
Sugarcane	Tops/leaves	Spread in the field	0.20	829 510
	Bagasse	Processing plant	0.30	68 662
Rice	Straw	Spread in the field	1.14	1 141 998
	Husk	Processing plant	0.21	210 368
Oil Palm	Empty bunches	Processing plant	0.25	409 400
	Press Fibres	Processing plant	0.13	212 888
	Fronds	Spread in the field	2.60	4 262 127
	Shell	Processing plant	0.05	81 880
Plantains	Stipe (false trunk)	Spread in the field	2.50	3 899 425
	Leaves	Spread in the field	0.20	311 954
	Empty fruit bunches	Processing plant	0.33	519 918
Banana	Stipe (false trunk)	Spread in the field	2.50	759 124
	Leaves	Spread in the field	0.22	67 471
	Empty fruit bunches	Processing plant	0.33	101 206
Cocoa beans	Pods	Spread in the field	1.50	2 036 531
Maize	Cob	Processing plant	0.26	252 307
	Husk	Processing plant	0.40	168 205
	Stover	Spread in the field	1.96	1 248 794
Cotton	Hull/shell	Processing plant	0.42	83 949
	Stalk	Spread in the field	3.40	680 360
Coconut	Fronds	Processing plant	0.47	69 720
	Husk	Processing plant	0.35	51 593
	Shells	Processing plant	0.12	17 689
Coffee	Husk	Processing plant	0.46	41 929
Cashew nuts	Shells	Processing plant	0.50	191 000

Source: Ministry of Agriculture and Bioenergy Working Group

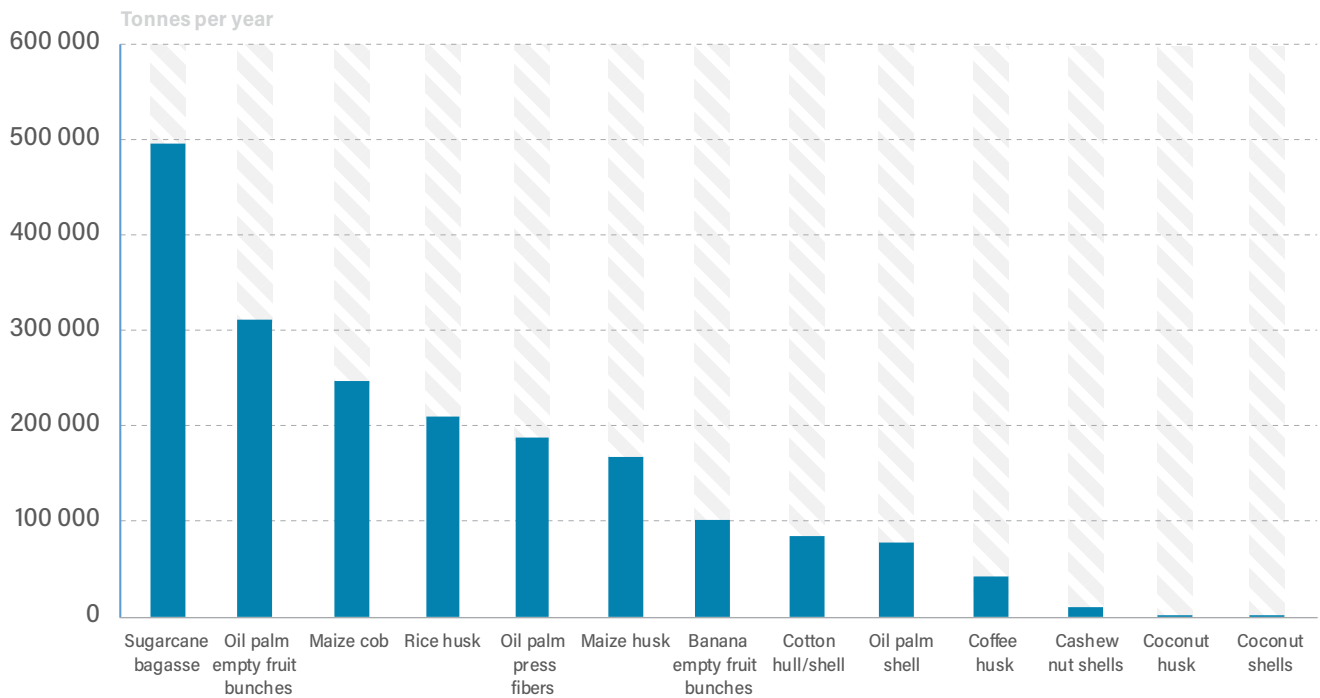
Having defined how much residues are produced per crop, it is necessary to understand if these residues are available for bioenergy production or already in use. As a result, the amount of residues potentially available for bioenergy production are calculated net of current residue uses,⁴ see **Figure 9** and **Figure 10**. Current uses for the residues include the following:

- Residues left in the fields to maintain soil fertility prevent soil erosion
- Animal feed/bedding
- Income generation
- Other uses

The analysis of residues produced in the processing plants included 10 crops and 15 types of residue **Table 2**. Based on the reported data (see **Annex 1** for availability shares), the residues with the highest availability are sugarcane bagasse, empty fruit bunch from oil palm and maize cob with volumes that range from 250 000 to 500 000 tonnes per year (tonnes/year). However, rice husk, oil palm press fibres and maize husk also show high availability (**Figure 9**).

⁴ The information used for the analysis regarding the residue-to-crop ratios and current uses for each crop was provided by the Ministry of Agriculture of Côte d'Ivoire. Data that was not available was collected through a review of existing studies and in consultation with local experts in the country. The sources and values of the data used is presented in **Annex 1** and **Annex 2**

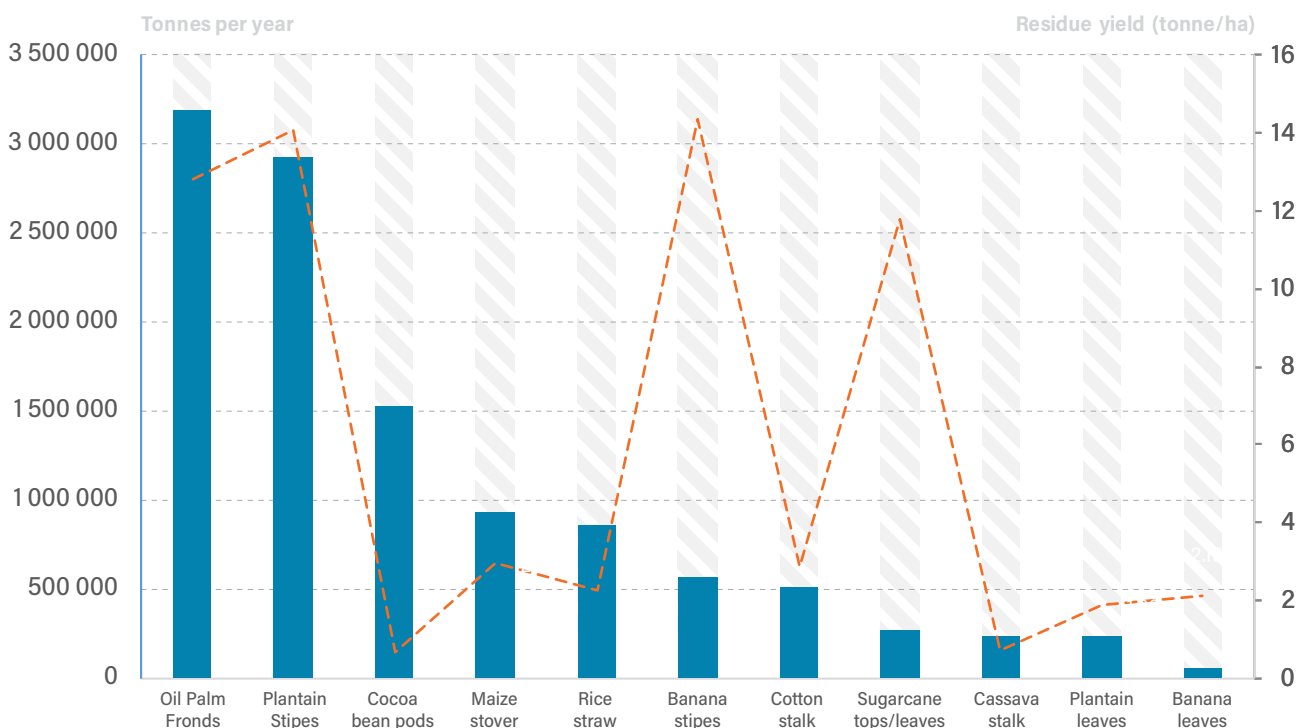
FIGURE 9. Availability of processing plant residues



Source: BEFS RA Analysis – Agricultural residues tool

The analysis for residues left spread in the fields included 9 crops and 11 types of residues as seen in **Figure 10**, (see **Annex 1** for the availability shares). The residues with the highest availability are oil palm fronds, plantain stipes and cocoa bean pods, followed by maize stover and rice straw (**Figure 10**). Overall, the residue availability for oil palm frond and plantain stipes is in the range of 3 000 000 tonnes/year, while for cocoa bean pods it is in the range of 1 500 000 tonnes/year. Maize stover, rice straw, banana stipes and cotton stalk are available in amounts between 500 000 and 1 000 000 tonnes/year.

FIGURE 10. Availability of residues spread in the fields

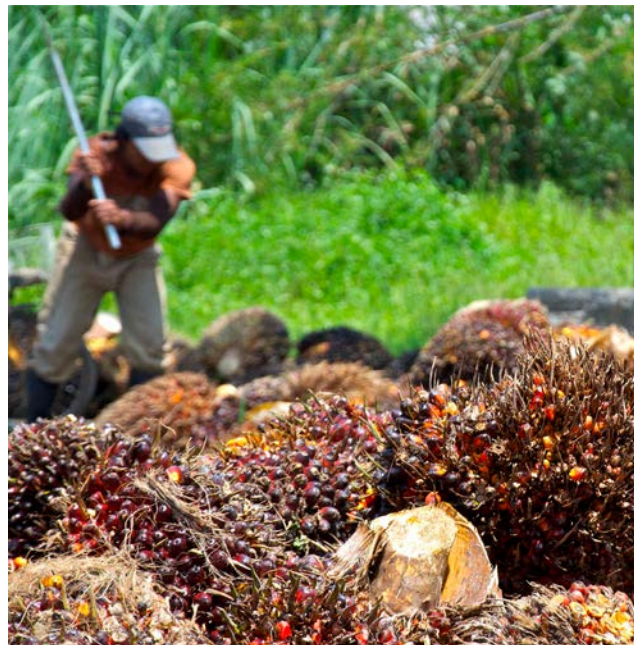


Source: BEFS RA Analysis – Agricultural residues tool

In the case of residues spread in the field, the residue yield is also an important parameter and this is presented in **Figure 10**. The residue yield is a measure of how scattered the residues would be. The higher the residue yield, the more concentrated the residues. Thus, the optimal option would be represented by high availability and high residue yield. Plantain stipes and oil palm fronds cocoa pods and maize stover are available in the largest amounts. Oil palm fronds and plantain stipes are also more concentrated, while cocoa pods and maize stover are very scattered. Banana stipes and sugarcane tops and leaves are also concentrated residues, but availability is low.



ICCFO (https://commons.wikimedia.org/wiki/File:Cocoa_farmers_during_harvest.jpg), <https://creativecommons.org/licenses/by-sa/4.0/legalcode>



Palm Oil Fruit Harvest by Craig Morey is licensed under CC BY-SA 2.0

Forest harvesting residues

The amount of forest harvesting residues that are available for bioenergy production are calculated based on (i) annual roundwood production, (ii) the rate of felling removals, (iii) the percentage of residues that are already used, and (iv) the percentage of residues that can be collected at a reasonable price. The residues are classified as bark, branches and various cut-offs. Foliage is excluded as it is assumed to be left in the forests for soil fertility and biodiversity conservation purposes.

In order to estimate the potentially available forest harvesting residues, national statistics on roundwood production as well as global databases on forestry production and trade from FAOSTAT, the UN Comtrade Database, the European Timber Trade Federation (ETTF) and the International Tropical Timber Organisation (ITTO) were used.

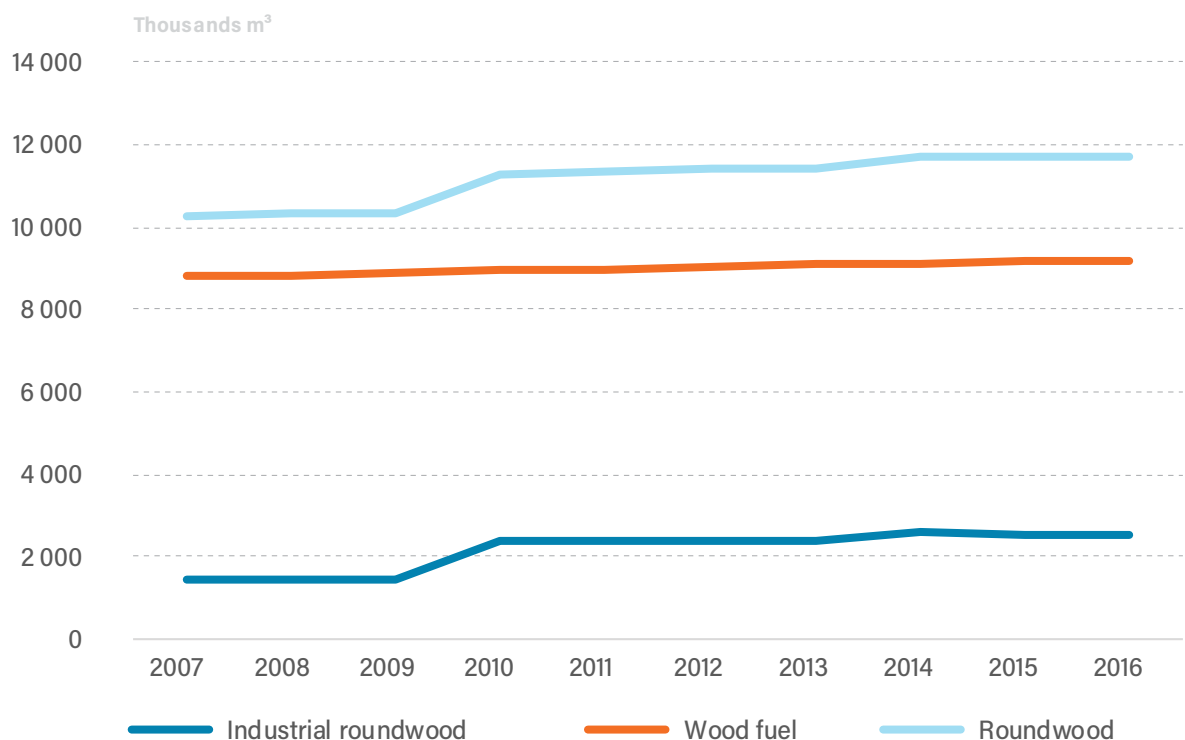
The most recent data available on volumes of industrial roundwood production published by the national statistical office is for 2012. Export data is available for 2012 and 2013. The latest available energy balance includes information on wood charcoal and fuelwood consumption for energy purposes in 2012. It also provides comparisons with the equivalent consumption in 2011. Given that more recent data was not available in the national statistics, FAOSTAT was also used in the context of screening trends on forestry use.



Palm Tree Forest by Miwok is licensed under CC0 1.0

The FAOSTAT forestry database provides a long-term data series on roundwood production, including both industrial roundwood and woodfuel. **Figure 11** shows the production trends over the last ten years. The volumes of woodfuel production have been slightly increasing over the years, while volumes of industrial roundwood stabilised at around 2.5 million m³ in 2010.

FIGURE 11. Industrial roundwood, wood fuel and total roundwood production in Côte d'Ivoire



Source: FAOSTAT, 2018

Considering the existing trends in roundwood production (industrial and woodfuel), 2016 was taken as the reference year for the assessment of potentially available harvesting residues. This is also in line with the existing trends of charcoal and fuelwood demand.

Industrial roundwood production was 2.5 million m³ in 2016, while that of woodfuel was 9.2 million m³ in that year. The rate of felling removal indicates the percentage of the tree that is removed from the

felling site. The average rate of felling removal is assumed to be 55.5 percent for industrial roundwood and 85 percent for woodfuel, in line with the assumptions of the BEFS RA tools. Due to lack of available data for Côte d'Ivoire, the tool's default for the rate of felling removal is used for woodfuel, while the rate of felling removal for industrial roundwood is based on information obtained by the ITTO Project in Ghana (International Tropical Timber Organization (ITTO), 2004).⁵

The percentage of residues that can be collected at a reasonable price reflects accessibility (for example, infrastructure, morphology of terrain, etc.), practicality of collection (size of branches and cut-offs, etc.) and labour availability. Due to lack of country-specific information, the tool provided default values of 60 percent for branches and various cut-offs and 50 percent for bark.

Finally, according to local experts in Côte d'Ivoire, 85 percent of woodfuel harvesting residues and 50 percent of industrial roundwood harvesting residues are currently collected and used. Based on these assumptions, the quantity of residues from non-coniferous forests that are potentially available for bioenergy production was estimated to be slightly more than 311 500 tonnes per year (**Figure 12**).

Wood processing residues

The calculation of the available wood processing residues for bioenergy production is based on the (i) annual sawnwood production, (ii) the average efficiency of sawmills and (iii) the portion of residues already used for other purposes. The types of wood processing residues produced are divided between sawdust, slabs and chips.

According to FAOSTAT, 871000 m³ of sawnwood was produced in 2016. From both the data on sawnwood production and the average efficiency of sawmills, the quantity of residues that were generated during wood processing activities can be determined. For Côte d'Ivoire, 45 percent of all wood processed in sawmills is finally converted into sawnwood, while the rest are residues in the form of sawdust (8 percent), slabs and chips (39 percent) and losses for reasons including shrinkage (8 percent).⁶

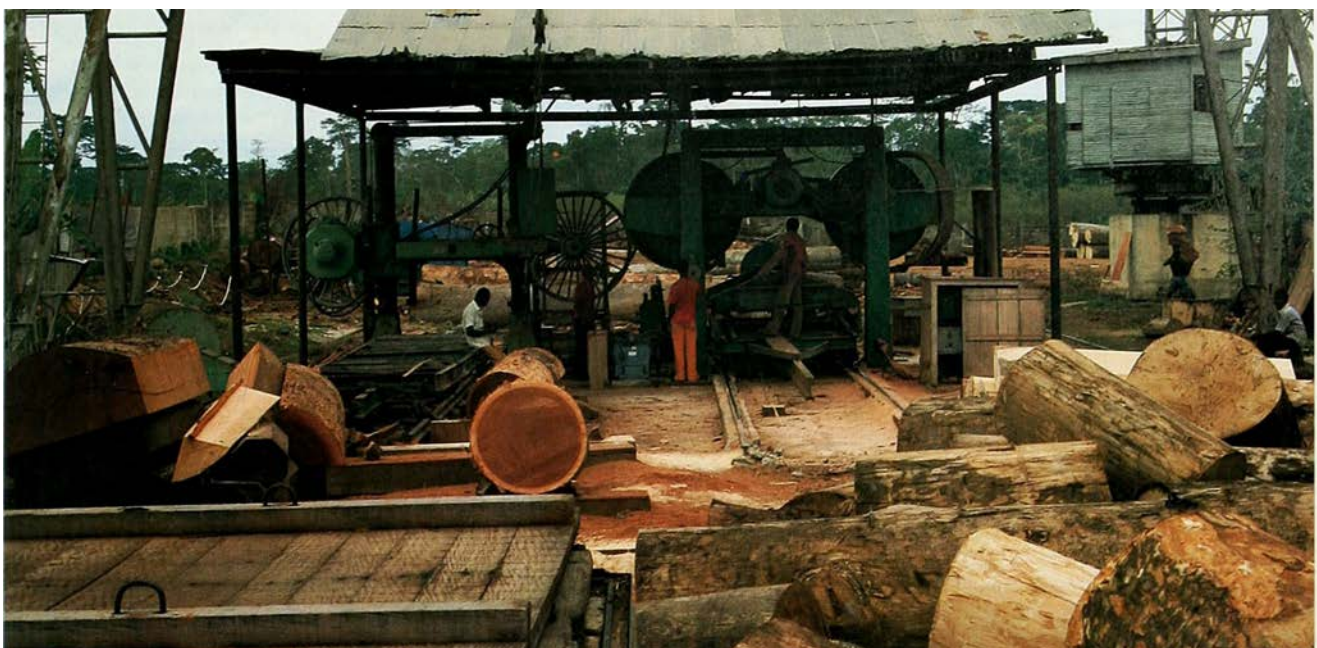


Image from page 64 of "The Conservation Atlas of Tropical Forests: Africa" (1992)

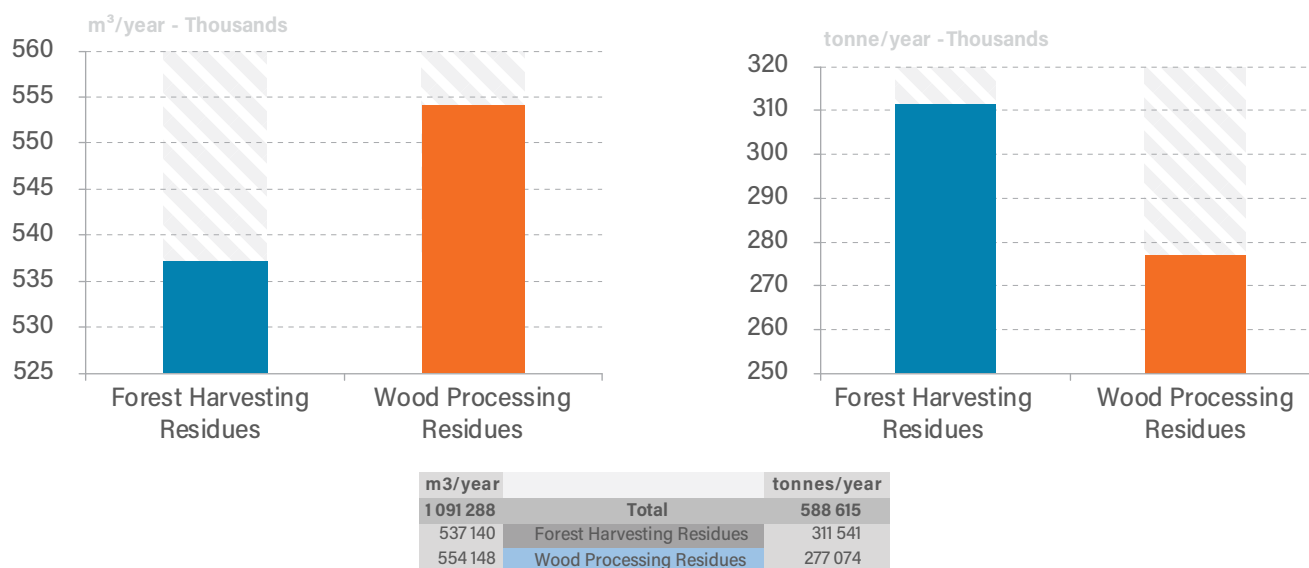
⁵ The ITTO Project "Enhancing industrial and community utilization of wood residues through briquette and charcoal production for environmental and livelihood improvement in Ghana" characterizes the forestry industries in Ghana. This value has been used in the absence of a more precise value for Côte d'Ivoire due to the similarities between both countries in terms of the type of forests and the tools used during forest harvesting activities.

⁶ Due to lack of country-specific information for Côte d'Ivoire, the results from the ITTO Project in Ghana were used for the average efficiency of sawmills due to similarities in the equipment and the scale of the sawmills.

It is important to consider the portion of residues already used for other purposes, such as the production of other wood products, the use of wood in the construction sector, energy, and so on. Through consultations with local experts in Côte d'Ivoire, the portion of residues already used was set at 20 percent for sawdust and 43 percent for slabs and chips. Residues are used for animal bedding, arts and crafts, and combustion in the same sawmills to produce energy.

Based on these data sources and assumptions, the quantity of wood processing residues potentially available are estimated to be just over 277 000 tonnes of residue/year (**Figure 12**).

FIGURE 12. Summary of the potential quantity of woody residues available annually for bioenergy purposes in Côte d'Ivoire



Source: BEFS RA Analysis – Woodfuel tool

Techno-economic assessment: off-grid rural electricity generation options

Once the amount of biomass potentially available for energy production has been estimated, the second step in the analysis is to carry out the techno-economic assessment. This component of the assessment aims to determine if off-grid electricity produced from the selected feedstock, through gasification and combustion technologies, can be economically and technically viable. Three representative plant sizes are considered. The types and amount of feedstock are the result of the biomass assessment, the first step of the analysis. The technoeconomic assessment includes an estimation of:

- the production costs per kWh and the investment requirement per representative plant size;
- the potential number of biomass-based combustion and gasification plants that can be developed;
- the number of households that could be supplied with electricity from these systems;
- the potential number of jobs that could result from the development of the plants.

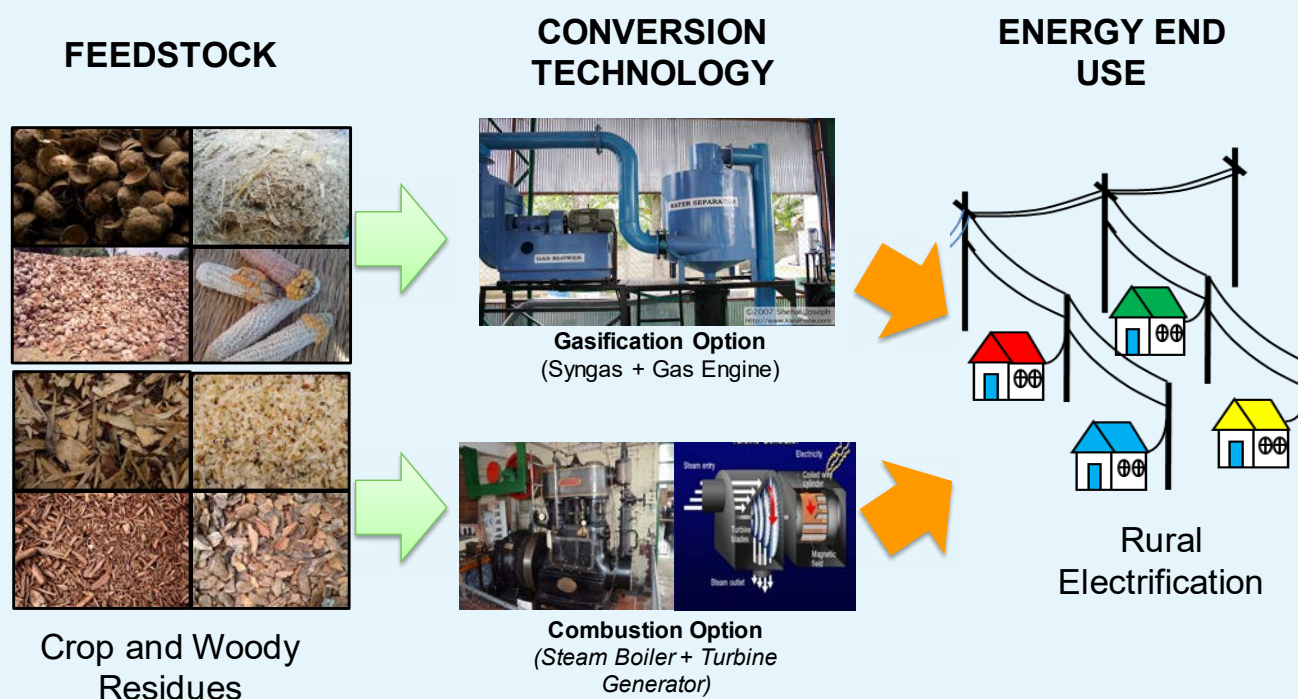
In terms of economic viability when considering off grid electricity generation options for rural areas, once the production costs and investment requirements are estimated, the biomass based system is compared to a standard off grid diesel generator. Two key parameters are needed to carry out the comparison: (i) the average electricity consumption level by rural households (ii) the current price of electricity in rural areas. These two parameters allow to compare the biomass based system with the standard diesel based generator. The information and data used in the analysis was provided by the relevant governmental institutions of Côte d'Ivoire. The details of the sources of information is presented in **Annex 1**.

Technology Box - Off-grid rural electrification technologies

Off-grid rural electrification technologies are an attractive way of providing electricity in rural, unelectrified, sparsely populated areas. Off-grid technologies are usually considered where an extension of the national grid is not feasible.

The use of off-grid technologies is widely used in developing when there are a limited coverage of national electricity distribution networks. The systems most commonly used are diesel power generators, given the relatively low investment cost of the equipment and the often-subsidized fuel prices. However, these systems can face problems related to fuel supply and high operating costs.

Biomass power technologies are an alternative to diesel generators that can use locally available resources to produce electricity. Combustion and gasification systems are the most commonly used biomass power technologies. The combustion technology burns biomass to produce steam which drives a turbogenerator to produce electricity. Gasification systems partially burn biomass to generate a gas mixture that is subsequently burned in gas engines to produce electricity.



The benefits of biomass off-grid technologies include:

- Renewable energy using a locally available source (biomass).GHG emissions reduction.
- Less dependency on fossil fuels.
- Adds value to an agricultural crop by using its residues.
- However, off-grid biomass technologies also have limitations: Capital investment and installation costs are higher than for traditional diesel generators.
- Additional labour may be required for collection and pre-treatment of residues.
- The combustion or gasification system must be selected considering a series of factors such as the scale of the plant, the energy demand and the characteristics of the biomass to be used for feedstock and other uses.

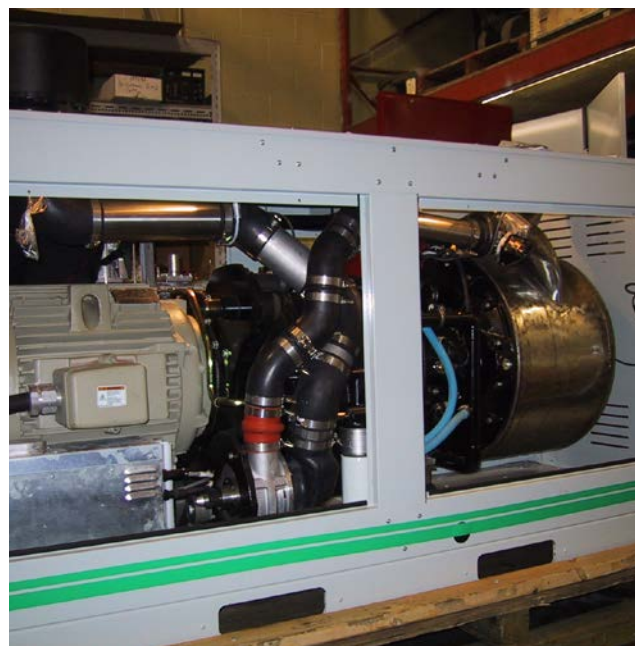
Additionally, some of the key parameters that affect the feasibility of these systems are:

- Subsidies and the price of diesel for traditional diesel power systems.
- Cost at which the biomass to be used as feedstock can be obtained. This includes the cost of collection, pre-treatment and/or the sale price.
- Access to financing for the purchase of these systems.

These key parameters are considered in the BEFS assessment.



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Electricity consumption per household

The average household consumption of electricity in rural areas is needed to determine the number of households that a combustion or gasification system can supply. The average consumption of 200 kWh per month was estimated as the average electricity demand for a rural household. This was based on the average supply of electricity produced by off-grid systems in operation in the country and the electricity consumption profile shown in **Table 3**.

TABLE 3. Average electricity consumption profile for a rural household in Côte d'Ivoire

Electrical devices used in an average rural household	Electrical devices used in an average rural household	Electrical devices used in an average rural household	Electrical devices used in an average rural household	Electrical devices used in an average rural household	Electrical devices used in an average rural household	Electricity consumption	
						kWh/day	kWh/month
TV color 25 inch	110	100%	1	8	30	0.88	26.40
TV color 14 inch	60	100%				0.00	0.00
Computer	237	100%	1	4	30	0.95	28.38
Fan 16 inch	40	100%	1	6	15	0.24	3.60
Air conditioner (9 000 BTU)	880	100%				0.00	0.00
Electrical iron	1 000	100%	1	2	12	2.00	24.00
Rice cooker	530	100%				0.00	0.00
Microwave	1 200	100%				0.00	0.00
Clothes washer 5 kg	305	80%				0.00	0.00
Electrical boiler	650	100%				0.00	0.00
Refrigerator	390	30%	1	24	30	3.28	98.31
Electrical water shower	4 000	100%				0.00	0.00
Fluorescent lamp (ceiling T5)	28	100%	2	6	30	0.34	10.08
Compact fluorescent lamp T5	14	100%	2	6	30	0.17	5.04
User defined appliance	35	100%	1	4	30	0.14	4.20
TOTAL						7.99	200.01

Source: BEFS RA Analysis – Country Status tool⁷

⁷ The profile uses as reference the average consumption of 55 off-grid diesel systems currently operating in Cote d'Ivoire. The more typical system works under the following parameters: 75 kW system working 2400 hours per year (8 hours per day) supplying in average 75 households or 400 people. Information retrieved from the report of activities for 2015 of ANARE (Autorité Nationale de Régulation du secteur de l'Electricité de Côte d'Ivoire (ANARE), 2015)

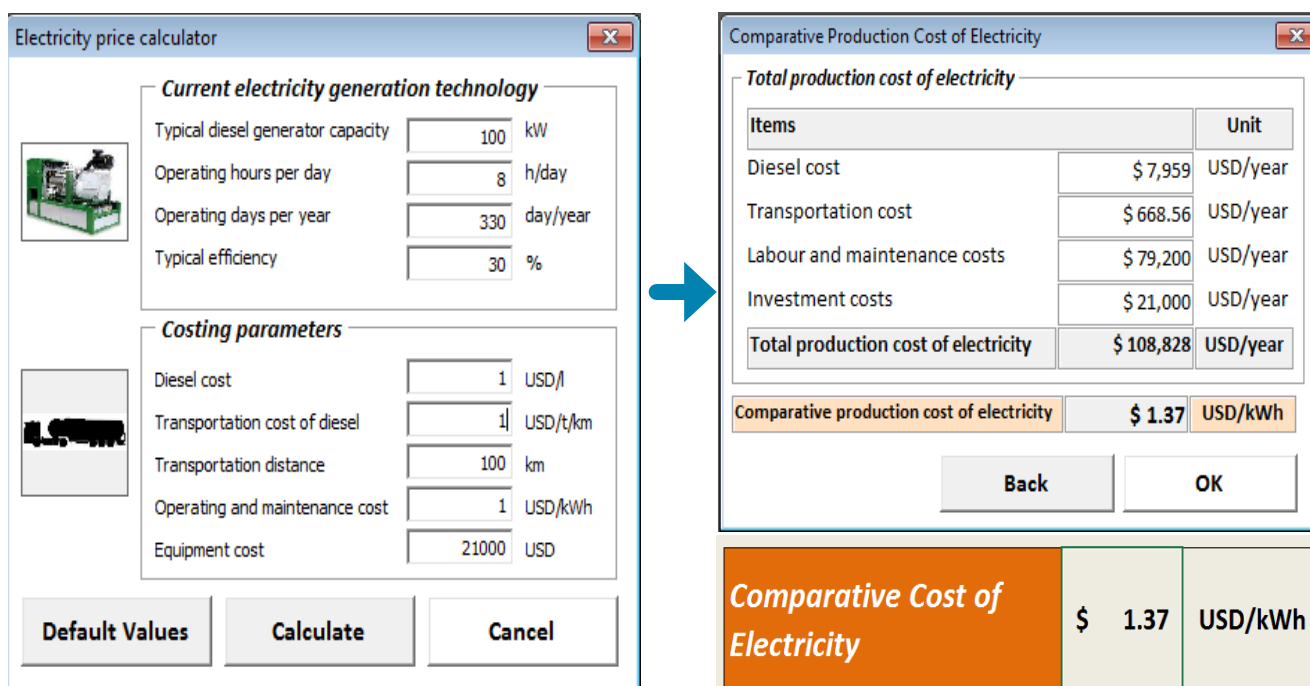
The price of electricity in rural areas

In the case of Côte d'Ivoire, off-grid rural electrification is almost exclusively carried out with diesel power systems. Given the current use of diesel based electricity generation systems, the gasification and combustions technologies have to be assessed against this reference system. For this comparison, an electricity production cost is needed. This was estimated to be 1.37 US\$ per kWh for a typical diesel system, considering local operating parameters as listed in **Figure 13**.

As a result, in order to be economically competitive, the biomass based gasification and combustion options should be able to produce electricity at a lower cost compared to the diesel generators.

As explained above, the techno-economic analysis was carried out for each type of residue for both combustion and gasification technologies. The analysis is based on three predefined plant sizes, namely 10 kW, 40 kW and 100 kW, to allow for comparison across options. Three series of results are presented: (i) costs and investment, (ii) technical and operational output, and (iii) financial analysis. Examples of the results for a combustion and a gasification system using cassava stalks are shown in **Annex 3**.

FIGURE 13. Cost of electricity with an off-grid diesel power system in Côte d'Ivoire



Source: BEFS RA Analysis – combustion and gasification tools screenshot taken from BEFSRA combustion tool

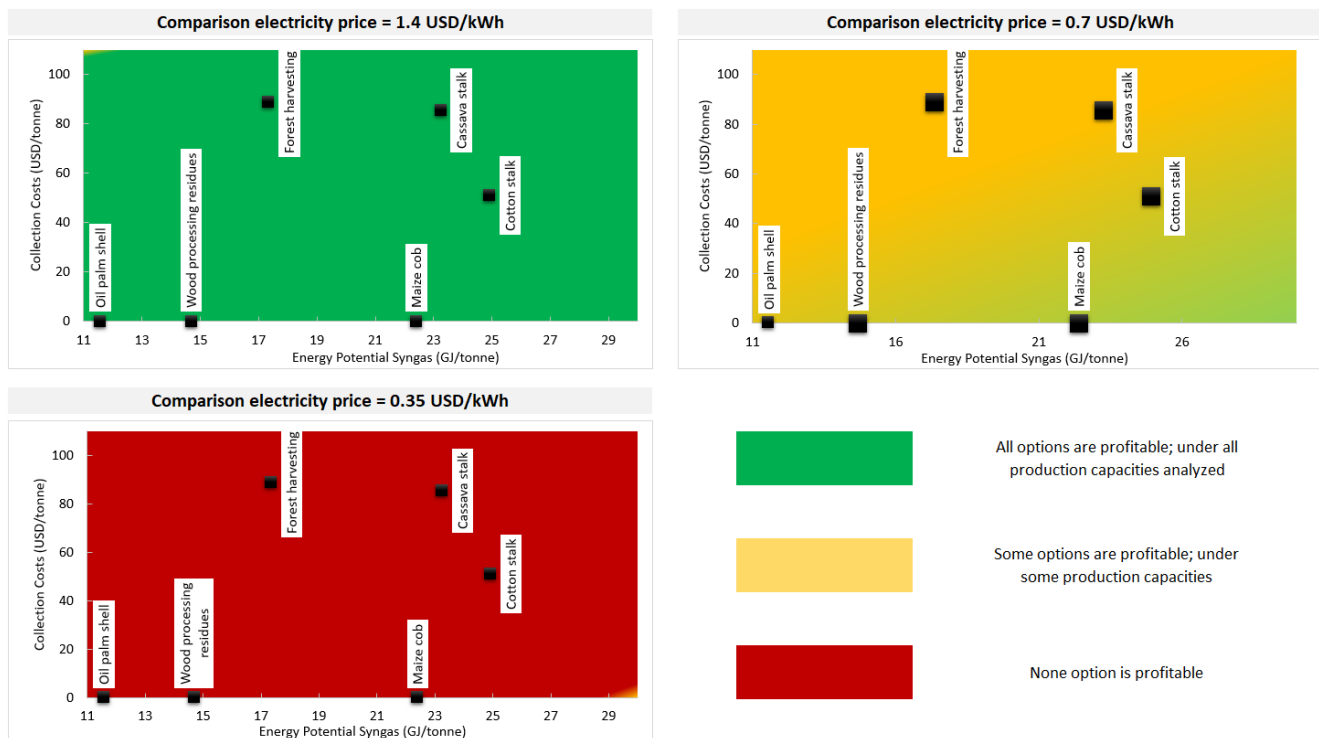
Results: Off-grid Rural Electricity Generation Options

The feasibility of each option is determined by a financial analysis. The financial analysis depends on the electricity price in rural areas (i.e. the estimated comparison price, 1.37 USD/kWh) and the costs of electricity production in the biomass power plants. Based on these parameters, the net present value (NPV) was calculated for all feedstock options, for the three generation capacities (10 kW, 40 kW, and 100 kW). These NPV results were then used to develop so called 'profitability zones' maps' (PZM). The PZM maps are a graphical representation of which production conditions can make the use of certain feedstock profitable, while accounting for the feedstock energy potential and costs. The maps present three zones marked in different colors, which change according to a scoring system. The scoring system is based on the number of production capacities with a positive NPV. Thus, the green zone includes feedstock with energy potential and/or feedstock cost that fulfill profitable production criteria for all plant sizes. The yellow zone encompasses feedstock that might be profitable under specific criteria and a set of plant sizes. The red zone contains feedstock which never meet the profitability requirements. This analysis also allows to identify the maximum price that producers could pay for a given feedstock, while keeping assuming a positive profit.

Each map considers a specific set of conditions represented by the price of electricity, productions costs, discount rates, etc. Due to this, the results are dependent on the conditions assumed and are representative of the context specified.

The price of electricity plays a central role in the analysis. To reflect possible differences in the price of electricity and the impact of this, it was considered three variations for electricity prices, namely the estimated electricity price for rural areas (1.37 USD/kWh) and then a 50 percent reduction of that and a 75 percent reduction. These reductions are arbitrary but illustrate the impact of a lower price of electricity.⁸

FIGURE 14. Profitability zones maps for gasification options



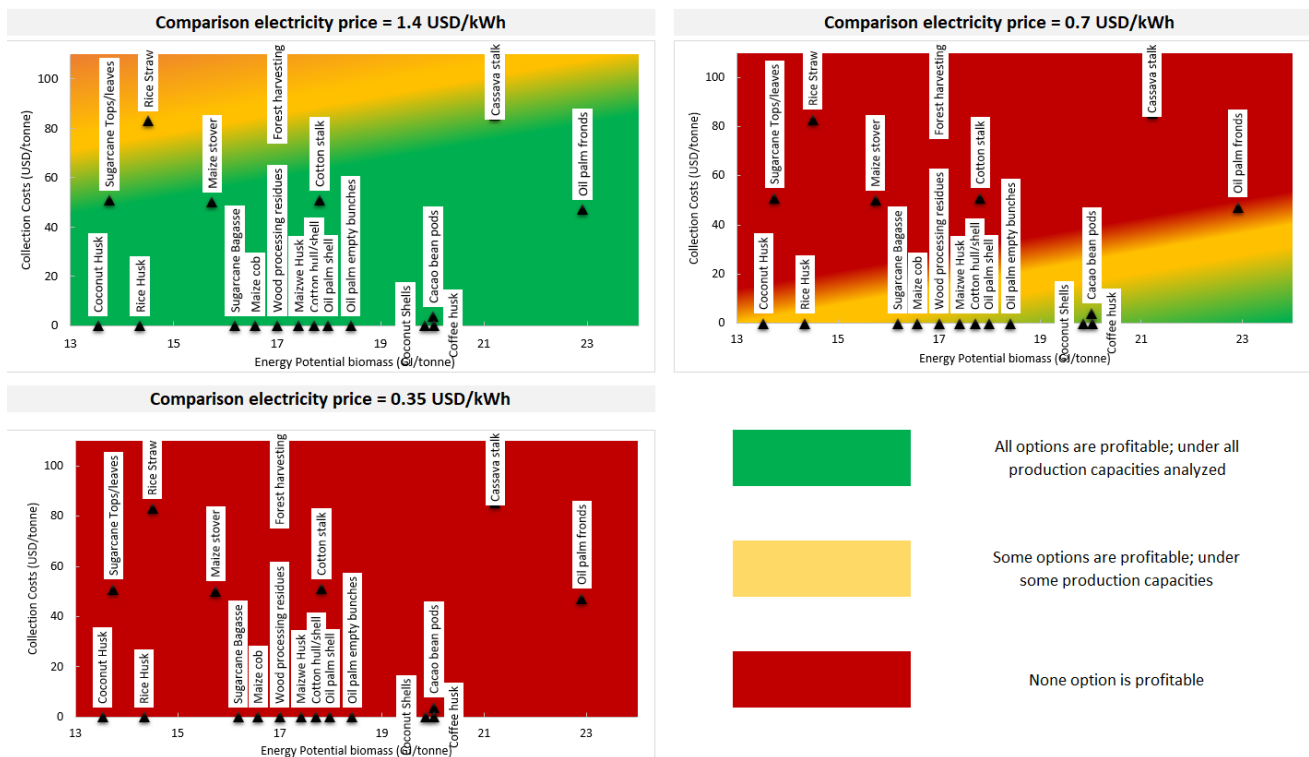
Source: Calculated from BEFS RA Analysis – Results of Gasification tool

As expected, the price of electricity that the system is compared to has a central role in defining which option may be profitable. When considering the calculated comparison price of 1.37 USD/kWh, all combustion and gasification systems using the range of feedstock analyzed could be profitable (see **Figure 14** and **Figure 15**). Once the price of electricity is reduced to 0.7 USD/kWh, the results show that for gasification plant sizes of 100 kW only, the system is still profitable. On the other hand, in the case of combustion, the green area of profitability options is smaller. This is due to the price of the electricity, the energy potential of the feedstock and the amount of electricity generated by this technology option. Thus, a large number of feedstock options would not be profitable using combustion technology. The exceptions would be coconut shells, cocoa bean pods, and coffee husks. The consumers' price of electricity cannot be reduced further (<0.35 USD/kWh) though as the gasification and combustion systems would no longer be profitable.

The analysis within the PZMs can also account for the difference in terms of the fuel used between gasification and combustion technologies. Thus, in the gasification case (see **Figure 14**), the energy potential axis represents the energy from the syngas obtained from the biomass, while in the combustion case (see **Figure 15**), the energy potential axis presents the direct energy extracted from the biomass. For example, oil palm shells in the combustion case is located at the point (18 GJ/tonne, 0 USD/tonne), where 18 GJ/tonne represents the low heating value (LHV) of the biomass. While, in the gasification case, this same feedstock is located at the point (12 GJ/tonne, 0 USD/tonne), given that the LHV is 12 GJ/tonne considering the syngas obtained from oil palm shells.

⁸ Prices of electricity can be a lot lower also in Africa. At times this can be due to subsidies. For example the average on grid price of electricity (production cost) in the region is 0.29 USD/kWh (World Bank, 2017).

FIGURE 15. Profitability zones maps for combustion options



Source: Calculated from BEFS RA Analysis – Results of combustion tool

Considering the potential profitability results for gasification and combustion technologies and the cases that are more resilient to changes in electricity prices, a set of preferred feedstock options were identified. These were used to estimate the potential number of households that could be supplied with electricity and the number of jobs that could be created with the installation of either combustion or gasification power plants. The summary of results shown in **Table 4** shows that more than 220 000 households could be supplied with electricity and that almost 21000 jobs could be created with the combustion based system.⁹ For gasification, around 45 000 households could be supplied and more than 4000 jobs could be created. This difference can be explained for the following technical reasons. The first reason lies within the energy extracted from the feedstock. In the combustion process, all the biomass is burnt directly, while in gasification the feedstock is first transformed into syngas and then used to produce electricity. A better quality of fuel is produced through the gasification process, but in reduced quantities, compared to combustion. The second reason lies within the suitability of feedstock for gasification or combustion. While a wider range of feedstock can be combusted directly, only feedstock with specific characteristics can be used for gasification. As a result, eleven feedstock options are suitable for combustion, while only five feedstock are suitable for gasification. Given that a wider range of feedstock options can be used in combustion, more energy can be generated from this technology and therefore more electricity, more jobs and more households supplied.

The results shown in **Table 4** are based upon the assumption that the total available residues for bioenergy are used with only one of the technologies. That is, if a type of residue is suitable for use in both combustion and gasification, such as cassava stalk, then the results show values under combustion that assume all of the cassava stalk was used in combustion and none was used in gasification and vice versa.

⁹ The analysis only takes into account the jobs created in the biomass power plants. A number of jobs would also be created in the collection, transportation of feedstock, etc. However, more information would be required in order to make that estimate.

TABLE 4. Number of households supplied with electricity and number of jobs created with biomass off-grid rural electrification technologies according to feedstock

Crop	Type of residue	Number of households supplied (100 kW plant)		Jobs created (100 kW plant)	
		Combustion	Gasification	Combustion	Gasification
Coconut	Husk	0	0	0	0
Coconut	Shells	0	0	0	0
Cassava	Stalk	12 422	9 307	1 136	856
Sugarcane	Bagasse	19 711	-	1 808	-
Rice	Husk	7 419	-	680	-
Oil Palm	Empty bunches	14 090	-	1 296	-
Oil Palm	Shell	3 440	1 494	312	136
Cocoa beans	Pods	75 195	-	6 920	-
Maize	Cob	10 277	9 486	944	872
Maize	Stover	36 251	-	3 336	-
Maize	Husk	7 202	-	656	-
Cotton	Stalk	22 352	21 373	2 056	1 968
Coffee	Husk	2 059	-	184	-
Wood processing residues	Slabs, chips, sawdust	11 495	6 805	1 054	626
TOTAL		221 913	48 465	20 382	4 458

Source: BEFS RA Analysis – Results of the Combustion and Gasification tools

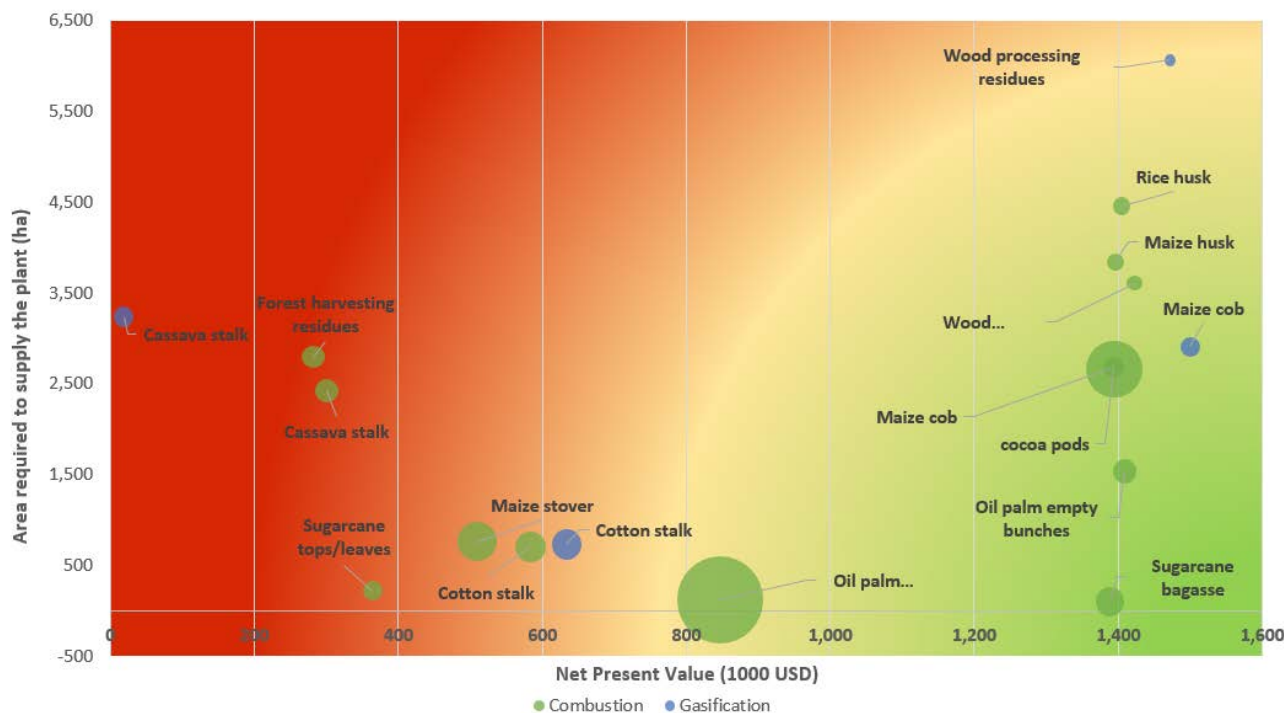
Overall, results for the number of households that can be supplied with electricity are directly related to the availability of biomass that can supply the electricity production plants. For combustion technology, the types of residues that have the potential to produce the greatest impacts on access to electricity are cocoa beans pods with more than 75 000 households supplied, while cotton stalk could supply more than 22 000 households. Maize stover, cotton stalks and sugarcane bagasse would each supply between 10 000 and 22 000 households.

For gasification technology, the types of residues that have the potential to produce the greatest impacts on access to electricity are cotton stalks with the potential to supply approximately 21 000 households, while maize cobs and cassava stalks could each supply 9 000 households. Wood processing residues and oil palm shells could each supply between 1 500 and 7 000 households.

Given the large number of factors involved in the analysis, **Figure 14** presents an aggregated combination of the results. **Figure 16** compares the results for both combustion and gasification technologies for all feasible feedstock options for a 100 kW plant. The figure also takes into consideration the area needed to cultivate the crop to provide the necessary feedstock for the power plant, as well as the net present value. The size of the bubbles represents the number of households that can potentially be supplied with electricity when using all available feedstock (actual values shown in **Table 4**).

The most suitable types of residue offering the greatest impact are oil palm fronds, cocoa pods, sugarcane bagasse, maize cobs and oil palm empty fruit bunches for combustion. For gasification, suitable types of residue are maize cobs and cotton stalks.

FIGURE 16. Comparison of the NPV, area of cultivation required to supply the plant with the necessary feedstock quantity, and the number of households potentially supplied with electricity for each type of residue



Source: BEFS RA Analysis – results of the combustion and gasification tools

Analysis combustion vs gasification

As shown in **Figure 16**, there are four types of residues that can be used either with combustion or gasification technology. These are cassava and cotton stalks, maize cobs and wood processing residues. The following analysis seeks to determine the most appropriate technology to be used according to the feedstock type.

Figure 15 compares the cost of electricity production with each technology and for each residue type. There is a general trend that the costs of production of electricity decrease as the scale of the plant increases because of economies of scale. When comparing both technologies for the 10-kW plant, the combustion option always has a lower electricity production cost than the gasification option, for all types of residue. This situation remains the same for the 40-kW plant though the gap between the two costs is smaller. For the 100-kW plant, the situation changes as gasification offers a lower electricity production cost than combustion, for cotton stalks, maize cobs and wood processing residues.

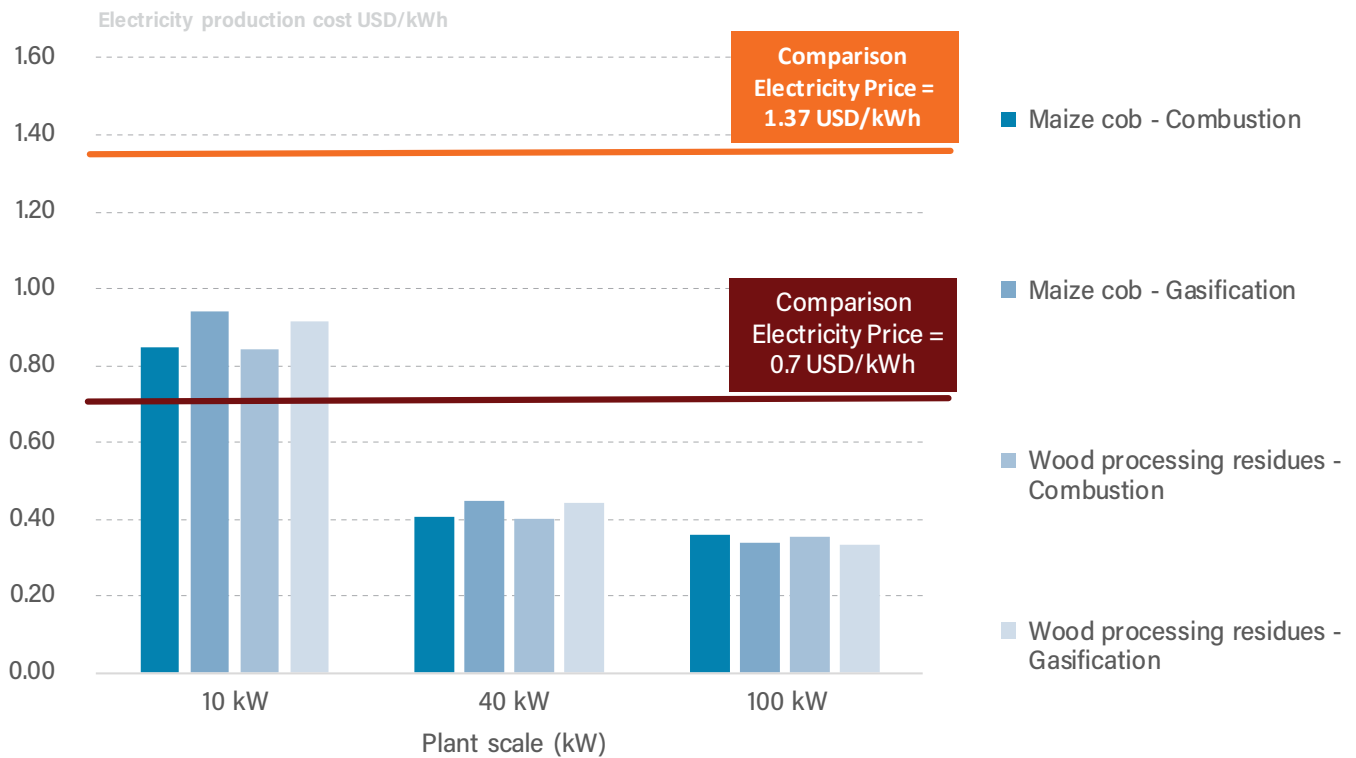
Finally, when comparing the cost of electricity production for each option with the diesel alternative (1.37 US\$/kWh), larger-scale plants are preferable. Using the case of cassava stalks as an example, the production cost of electricity for a 40-kW combustion plant is lower than the equivalent cost of electricity through diesel (1.37 US\$/kWh). However, an equivalent 40-kW gasification plant offers a higher electricity production cost and is therefore not competitive.

Given the number of combinations possible, two feedstock options are selected among the best performing feedstock set, to illustrate levels and trends in production costs. **Figure 17** compares the cost of electricity production for gasification and combustion using maize cob and wood processing residues. Due to the effect of economies of scale, the costs of production of electricity decreases as the scale of the plant increases. When comparing both technologies, the 10-kW combustion plant option always has a lower cost of production of electricity compared to gasification, for all types of residues. This situation remains the same for the 40-kW plant, however the gap between the two costs is far smaller. For the 100-kW plant, the situation changes as gasification offers a lower cost of production of electricity than combustion for maize cobs and wood processing residues.

It is clear how all options would result profitable at the comparison electricity price of a diesel alternative (1.4 USD/kWh).

The PZMs analysis revealed that the lowest profitable comparison electricity price is 0.7 USD/kWh. A comparison of this electricity price with the electricity production cost for the selected alternatives shows that the 10 kW capacity would no longer be profitable, due to the resulting high production costs. As a result, both for the combustion and gasification case, plants would need to be larger 40kW.

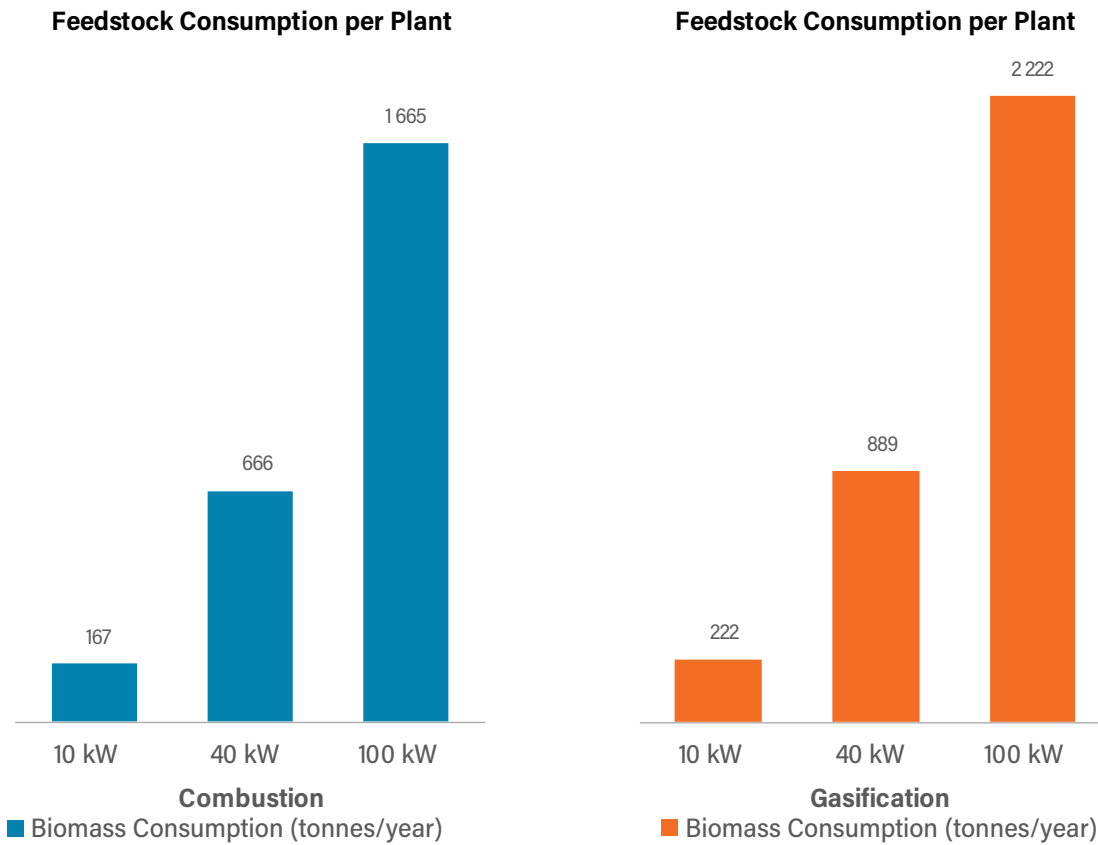
FIGURE 17. Comparison of the cost of production of electricity for combustion and gasification technologies



Source: BEFS RA Analysis – Results of the Combustion and Gasification tools

Figure 18 shows a comparison of feedstock consumption for combustion and gasification plants. At every scale, a gasification plant requires more feedstock than an equivalent combustion plant. This is because gasification plants self-consume a certain amount of electricity during operation and, therefore, require more feedstock in order to provide the same electricity output as combustion (**Table 3**).

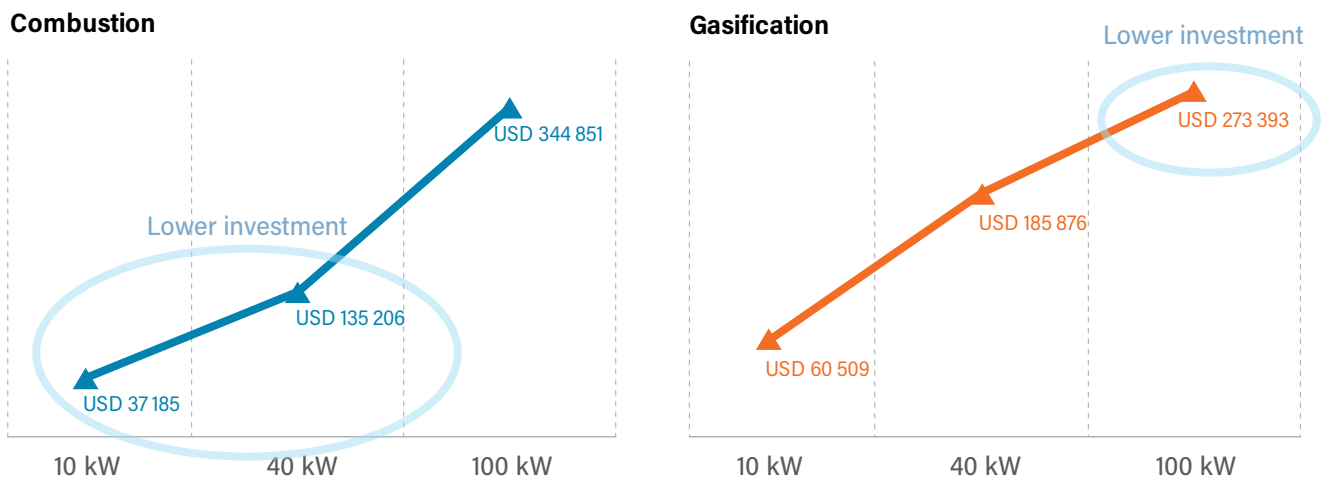
FIGURE 18. Feedstock consumption for combustion and gasification plants using cassava stalks



Source: BEFS RA Analysis – results of the combustion and gasification tools

Finally, **Figure 19** compares the level of capital investment required per plant according to technology. Smaller combustion plant sizes require less investment when compared to the equivalent gasification plant, while the opposite occurs for the larger 100-kW plant.

FIGURE 19. Comparison of capital investment required according to plant scale per technology type



Source: BEFS RA Analysis – Results of the Combustion and Gasification tools

The results shown in **Figure 16** to **Figure 19** indicate that gasification is competitive when considering larger power plants, depending on the suitability of the residue type for the technology considered. For this reason, gasification could be considered for 100-kW plants using cotton stalks and maize cobs. For all other types of residues and plant sizes, combustion is the most adequate technological solution.

Conclusion

Approximately 3.7 million do not have access to electricity in rural areas of Côte d'Ivoire. The results of the BEFS Rapid Appraisal show that under an optimistic scenario, in which all the crop and forest residues estimated as available could actually be used for the production of electricity, an estimated 2 million people could be supplied with electricity from the biomass based systems assessed. This supply would cover 57 percent of the people living in rural areas that currently do not have access to electricity.

The analysis assessed the feasibility of producing off grid electricity in rural areas from biomass based systems. Two technologies were considered: combustion and gasification. The availability of forest residues and crop residues for energy production were assessed, when accounting for other current uses.

Regarding the two technologies analysed, the results show the advantages of combustion technology due to its flexibility, including the adaptability for smaller scale options and the ability to use a wider variety of feedstock when compared to gasification. The gasification technology shows more competitive results for larger scale plants in which the amount of electricity required by the plant no longer influences the final feasibility of the system.

In relation to feedstock, the analysis shows how the types of residue that are produced in higher quantities are produced and found in the field. However, the costs of residue collection and its transport from the field to the biomass power plants are determining factors. In some cases these could make the use of certain types of residue unfeasible. For this reason, as a subsequent step, it would be necessary to carry out a detailed analysis on a case-by-case basis at field level that can verify actual availability and accessibility of the residues at local level.

The easiest options to promote are when residues are available in the same processing plants. This means low collection and transport costs and the most attractive financial results.

A useful parameter generated during the analysis for comparing different feedstock alternatives is the area required to provide the necessary feedstock to a biomass power plant. This parameter can help to identify sites where a more detailed assessment that includes a spatial analysis can determine if a project could potentially be developed.

In summary, the results shown indicate that gasification is competitive when considering larger power plants, depending on the suitability of the residue type with the technology. For this reason, gasification could be considered for 100 kW plants using cotton stalks and maize cobs. For all other types of residue and plant sizes larger than 40 kW, combustion is the most appropriate technological solution.

In terms of policy development, the analysis has shown that a series of options could be feasible when compared to the standard off grid diesel based option. As a next step, these options should be analysed in greater depth incorporating local and site-specific parameter.

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Useful links

BEFS Video

www.fao.org/news/audio-video/detail-video/en/c/11093/?uid=11093

BEFS Manuals

- ▶ **Bioenergy and Food Security Rapid Appraisal – User Manual: Forest Harvesting and Wood Processing Residues.**
www.fao.org/3/a-bp857e.pdf
- ▶ **Bioenergy and Food Security Rapid Appraisal – User Manual: Crops.**
www.fao.org/3/a-bp845e.pdf
- ▶ **Bioenergy and Food Security Rapid Appraisal – User Manual: Briquettes .**
www.fao.org/3/a-bp845e.pdf

ANNEX 1

Reported current uses by crop and residue type

Crop	Residue type	Residues produced	Left in the field	Animal feed and bedding	Energy production	Other uses	Available for bioenergy	Residues available
Cassava	Stalk	317 663	25%				75%	238 248
Sugarcane	Tops/leaves	359 600	25%				75%	269 700
	Bagasse	495 486					100%	495 486
Rice paddy	Straw	1 141 998	25%				75%	856 499
	Husk	210 368					100%	210 368
Oil Palm	Empty bunches	409 400			24%		76%	311 144
	Press Fibers	212 888			12%		88%	187 341
	Fronds	4 262 127	25%				75%	3 196 595
	Shell	81 880			5%		95%	77 786
Plantains	Stipe (false trunk)	3 899 425	25%				75%	2 924 569
	Leaves	311 954	25%				75%	233 966
	Empty fruit bunches	519 918				100%	0%	0
Bananas	Stipe (false trunk)	759 124	25%				75%	569 343
	Leaves	67 471	25%				75%	50 603
	Empty fruit bunches	101 206					100%	101 206
Cocoa beans	Pods	2 036 531	25%				75%	1 527 398
Maize	Cob	252 307			2%		98%	247 261
	Husk	168 205					100%	168 205
	Stover	1 248 794	25%				75%	936 595
Cotton seed	Hull/shell	83 949					100%	83 949
	Stalk	680 360	25%				75%	510 270
Coconut	Fronds	69 720	13%		45%	42%	0%	0
	Husk	51 593			10%	85%	5%	2 580
	Shells	17 689			75%	15%	10%	1 769
Coffee	Husk	41 929					100%	41 929
Cashew nuts	Shells	191 000				95%	5%	9 550

Source: The data was obtained from the Ministry of Agriculture or through expert meetings in the field.

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