Sustainable Thermochemical Valorization of Cashew Nut Waste in West Africa: Experimental Study and Evaluation of the Energy Potential in Côte d'Ivoire

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Abstract - The local shelling of cashew nuts in West Africa generates very abundant and troublesome waste for high-capacity processing units. In order to propose sustainable solutions to contribute to local energy production and to mitigate the difficulty of managing these agro-industrial residues, we carried out a thermochemical study of the cashew nut shells before evaluating the energy potentialities. Thus, the study showed that the pyrolysis of the cashew nut shells generates on average 17% cashew shell charcoal, 81% fuel gas and 2% inorganic matter. Analysis of the raw shells and shell coal resulted in Net calorific values (NCV) of 5,217 kcal/kg, 6,799 kcal/kg and 4,317 kcal/kg for the raw shells, shell charcoal and pyrolysis gas, respectively. For Côte d'Ivoire, West African country lied between latitudes 4° and 11°N, and longitudes 2° and 9°W, local shelling of cashew nuts can generate 49,331 to 116,352 tons of shells per year. The study of the energy potential showed that from the year 2018, the annual energy potential of this biomass in Côte d'Ivoire will evolve from 22,952 to 54,135 toe with a production capacity of 59.67 to 140.78 GWh of electricity and 8,386.27 to 19,780 tons of shell charcoal. More importantly, we note that the energy potential of the fuels available after cashew processing could increase from 20,364 toe to 48,031 toe per year in the coming years. The development of cashew nut shell pyrolysis in West Africa could therefore reduce the use of fossil fuels for power generation and deforestation, two of the main causes of local climate change.

Keywords: Cashew nut waste, Thermochemical valorization, Pyrolysis, Sustainable energy.

1. Introduction

From a general point of view, the foreseeable depletion of fossil fuels, the need to fight against global warming, the growing awareness for the protection of the environment and finally the consideration of sustainable development in energy policies have put renewable energies and mainly bioenergy at the heart of a strategic challenge for the future of our planet [1, 2].

Since the end of 1990, cashew nuts have become one of West Africa's most important export products [3]. This justifies the establishment of an increasing number of processing units, mainly in the regions of high production [4, 5]. Cashew nuts processing requires energy for both the brittleness of the nuts and the drying of the almonds after shelling [6]. For this purpose, in most processing plants, cashew nut shells from cashew nut shelling are used for energy production in the processing process and by direct combustion in boilers [3, 7]. However, not all cashew nut shells generated by shelling are valued due to their high abundance and therefore remain very bulky for agro-industrial units. Thus, in general, available cashew shells are burned in landfills [7]. Containing a liquid called CNSL (Cashew Nut Shell Liquid), the combustion of cashew shells in boilers and landfills generates a very abundant smoke that is very irritating to the eyes [6]. Current cashew nut waste management processes cause environmental pollution and are therefore a risk to human health [6]. However, biomass can be valorized by thermochemical processes [8] and can be a sustainable energy source [7, 9] and thus contribute to the mitigation of local climate change [10, 11]. It is therefore appropriate to integrate a process for the recovery of available cashew nut waste, adhering to the context of sustainable energy development in West Africa. Thus, the long-term objective of this study is to experiment the sustainable thermochemical valorization of cashew nut waste in order to encourage its integration into local energy networks. Specifically, this will consist to:

- Carry out an experimental study of a process for the thermochemical valorization of cashew nut shells adhering to the context of sustainable energy development in Côte d'Ivoire, the world's leading producer and first processor in the West African sub-region;
- Evaluate the energy values of the fuels generated by the thermochemical treatment;
- Evaluate the availability of cashew nut waste within the agro-industrial units and the energy potentialities of the thermochemical valorization in Côte d'Ivoire.

According to the results of previous studies by some authors, The gasification of raw cashew nut shells is problematic due to the presence of oil (CNSL) that flows out of the shells and condenses towards the cold zones of the gasifier [12, 13]. Beyond the technical performances (charcoal and fuel gas production), the first observations made on the pyrolysis of cashew nut shells suggest a reduction of atmospheric emissions. The use of a pyrolysis furnace eliminates the pungent and irritating odors that were emitted with the old practice of direct shell combustion and the fumes are practically invisible [6]. We therefore deduce that the valorization of cashew nut shells by pyrolysis is better suited to the context of sustainable energy development in Côte d'Ivoire.

2. Materiel and methods

2.1 Equipment and method for thermochemical treatment of cashew nut shells

2.1.1 Biological material: Cashew nut shell sample

For the various laboratory analyses, a total of 5 kg of raw cashew nut shells were sampled from a heap of a processing unit in Bouaké (SOBERY SA), city in central Côte d'Ivoire. The particles sampled have a dimension from 2 to 3 centimeters and are generated by shelling the raw cashew nuts. Figure 1 shows the shell sample used for the different laboratory analyses.

Figure 1. Image of the cashew nut shell sample used for analysis

2.1.2 Thermochemical study material and methodology

a) Presentation of material

Our studies were carried out on a pyrolysis furnace installed in one of the processing units in Bouaké (Côte d'Ivoire) as part of the implementation of the AGROVALOR project [7]. The material is a steel construction mainly made of 3 mm thick steel sheet and refractory. Figure 2 below shows the pyrolysis furnace used for the different tests.

Figure 2. Example of equipment used for the thermochemical treatment of cashew nut shells (Valorization of shells into pyrolysis gas for feeding a boiler)

b) Example of an experimental study method for the determination of the energy performances of an industrial pyrolysis furnace

The raw cashew nuts to be shelled are placed in three pots with a total capacity of 960 kg. The raw cashew nut shells (fuel) are progressively admitted into the reactor (cylinder) through the hopper, until the end of the embrittlement of the nuts. The burner mounted above the pyrolysis reactor allows the combustion of the gases generated by the pyrolysis of the shells to feed the boiler used to produce the steam needed to embrittle the raw nuts and to dry the almonds with skins after shelling. After the end of the combustion flame of the pyrolysis gas, the shell charcoal is left to cool for about five hours in the furnace before its extraction to prevent it from burning in contact with air. A total of two tests were carried out on the pyrolysis furnace for the embrittlement of 960 kg raw cashew nuts for a respective duration of 3h32min and 3h55min of the combustion flame of the pyrolysis gas at an average internal temperature of the furnace of 450°C. The pyrolyzed raw shells and shell charcoals were weighed using an industrial scale to estimate the various ratios (percentage) at the end of the experiment.

2.2 Equipment and methods for the characterization of different solid fuels

2.2.1 Proximate analysis

Proximate analysis can be used to determine the moisture content (M %), volatile matter content (VM %), ash content (A %) and fixed carbon content (FC %) of fuels [1, 5, 14]. It has been made according to the French standards NF EN 14 775 and NF EN 15 148 [1, 15]. The different values and rates (%) were determined using the appropriate equipment (oven, muffle furnace and electronic scale) and according to the recommended standards.

2.2.2 Ultimate (Elemental) analysis

Elemental analysis can be used to determine the chemical constituents of different fuels [1, 5]. The analyses have been carried out according to the NF EN 15 407 standard and with the help of an analyzer EDS (Energy Dispersive X-ray Spectroscopy).

2.2.3 Calorific values of fuels

a) Higher caloric value (HCV) and net caloric value (NCV) of solid fuels

The calorific value is determined by the principle of determining the HCV and calculating the NCV [16 – 18]. According to the DULONG model [16, 17], the HCV is expressed by the following equation:

$$\text{HCV (kcal/kg)} = [81.3\times C + 345.5 \times (H-O/8) + 22.2\times S] \quad (1)$$

With C, H, O and S, representing the mass percentages of carbon, hydrogen, oxygen and sulphur, respectively, determined by ultimate analysis of dry biomass.

For a dry biomass (without moisture), the relationship between NCV and HCV is given by the following relation [16, 17, 28]:

$$\text{NCV (kcal/kg)} = \text{HCV} - [54 \times H] \quad (2)$$

b) NCV of the pyrolysis gas

The estimation of the pyrolysis gas combustion flame energy is based on the material and energy balance between the pyrolysis furnace inputs and outputs [6, 18]. All the energy of the raw shells entering the furnace is removed in terms of the heat of combustion of the pyrolysis gases and the total energy of the recovered coals [6, 19]. Knowing the mass and NCV of the raw shells entering the furnace on the one hand, and the mass and NCV of the recovered coals on the other hand, we deduce by difference the energy potential of the pyrolysis gases. Thus, by neglecting (minimizing) the energy losses that can vary depending on the installation and equipment, we note that:

Energy (Shell) = Energy (Char-shell) + Energy (gas) [6, 28].

We deduce the approximate value of the Net Caloric Value of pyrolysis gas:

$$NCV_{gas\ (app)} = (M_{shell} \times NCV_{shell} - M_{char\text{-}shell} \times NCV_{char\text{-}shell}) / M_{gas} \quad (3)$$

With Mshell, Mcharcoal and Mgas representing respectively the mass of organic matter in the dry cashew nut shells (without moisture), the mass of shell charcoal and the mass of pyrolysis gas generated.

2.3 Methodology for evaluating the annual energy potential of available cashew shells

2.3.1 Method for assessing cashew nut waste availability

As part of the implementation of the project for the energy recovery of agro-industrial waste in Côte d'Ivoire (AGROVALOR) led by the Ivorian NGO AEDD and the French NGO Nitidæ, field studies were carried out in the various units in the Gbèkè and Poro regions and in the district of Abidjan. The various weighing operations were carried out using industrial scales. The data obtained allowed us to evaluate the average percentages of products generated by cashew nut shelling and the availability rate of the different wastes. Estimates of annual waste availability were then made on the basis of the data in the activity report of the Cashew Cotton Council of Côte d'Ivoire [4] made available to us.

2.3.2 Equation for calculating the annual energy potential of cashew nuts shells

a) Total energy potential of the shells generated by cashew nuts shelling of cashew nuts

The energy potential is calculated using national statistical data [4], the various net calorific values ($NCV_{char\text{-}shell}$ and NCV_{gas}) and the percentages by mass ($R_{charcoal}$ and Rgas) of the various fuels (pyrolysis gas and shell charcoal) in relation to the total mass of the shells to be recovered. Thus, the total annual energy potential (E_{total}) of the cashew nut shells expressed in ton of oil equivalent (toe) or kilocalorie (kcal) is calculated from the following equation:

$$E_{total}\ (kcal) = (R_{char\text{-}shell} \times NCV_{char\text{-}shell} + R_{gas} \times NCV_{gas}) \times M_{shells} \quad [20]$$

$$E_{total}\ (toe) = 10^{-7} (R_{char\text{-}shell} \times R_{char\text{-}shell} + R_{gas} \times NCV_{gas}) \times M_{shells} \quad (4)$$

With the different NCV expressed in kcal/kg and the mass of shells to be recovered (M_{shell}) expressed in kg.

b) *The energy potential of shell charcoal to be generated*

We deduce from equation 4 that the energy potential of the shell charcoal to generate:

$$E_{char\text{-}shell} = E_{char\text{-}shell-process} + E_{char\text{-}shell\text{-}avail}$$

$$E_{char\text{-}shell}\ (toe) = 10^{-7} (R_{char\text{-}shell} \times NCV_{char\text{-}shell}) \times M_{shells} \quad (5)$$

With $E_{char\text{-}shell\text{-}process}$, the energy potential of shell charcoal genered by the processing of cashew nuts and $E_{char\text{-}shell\text{-}avail}$, the energy potential of shell charcoal can be genered by the shells available after processing expressed in kg.

c) Energy potential of the pyrolysis gas to be generated (excluding cashew nuts transformation energy)

We deduce from equation (4) that the energy potential of the pyrolysis gas:

$$E_{gas\text{-}avail}\ (kcal) = (R_{gas} \times NCV_{gas}) \times M_{shell\text{-}avail}$$

$$E_{gas\text{-}avail}\ (tep) = 10^{-7} (R_{gas} \times NCV_{gas}) \times M_{shell\text{-}avail} \quad (6)$$

With $M_{shell\text{-}avail}$, the mass of shells available after cashew nuts processing expressed in kg.

2.4 Material and method for integrating the thermochemical recovery of cashew nut shells in energy networks in Côte d'Ivoire

2.4.1 Synoptic diagram

Figure 3 shows the process for the sustainable energy recovery of cashew nut shells from industrial pyrolysis furnaces.

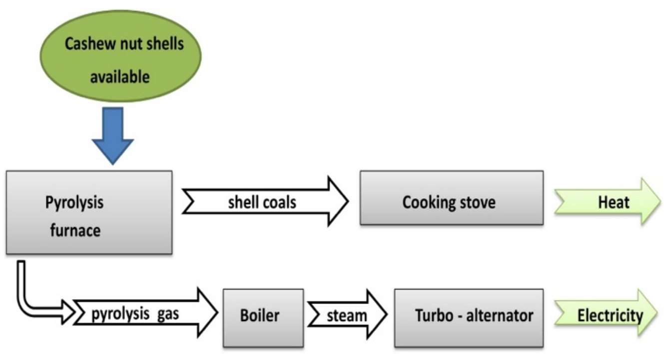

Figure 3. Schematic diagram of the sustainable energy recovery process for available raw cashew nut shells [20]

According to the results of previous studies, the heat generated by the combustion of fuel gas transforms the liquid water in the boiler into steam to drive the steam turbine generator and produce electricity [21 – 24]. Coal is used to produce heat for cooking energy [6, 11, 25]. In addition, according to ADEME data, the electricity efficiency (η_{elect}), by default, of conventional thermal power plants is estimated at 35% [20; 26; 27];

2.4.2 Method for assessing the annual potential for pyrolysis gas to be converted into electricity and the rate of contribution to the electricity mix

The potential for electricity production (E_{elect}) by the different devices is calculated from the following equation:

$$E_{elect}\,(kcal) = \eta_{elect} \times E_{gas\text{-}avail}\,(kcal) \qquad [20, 26]$$

$$E_{elect}\,(kwh) = [\, \eta_{elect} \times E_{gas\text{-}avail}\,(kcal)\,]/860 \qquad (7)$$

With $E_{gas\text{-}avail}$, the energy potential of the pyrolysis gas to be valorized (Energy potential of the pyrolysis gas to be generated, excluding cashew nuts transformation energy).

2.4.3 Methods for assessing the mass and rate of substitution of wood coal for cashew nut shell coal

Taking into account the material and energy balance [6], we deduce that the energy of the mass of cashew nut shell charcoal ($M_{char\text{-}shell}$) to be recovered is equal to that of the mass of charcoal to be substituted. The mass of substitutable charcoal ($M_{char\text{-}wood}$) is given by the following equation [6]:

$$M_{char\text{-}wood} \times NCV_{char\text{-}wood} = NCV_{Char\text{-}shell} \times M_{char\text{-}shell}$$

$$M_{char\text{-}wood} = (\, NCV_{Char\text{-}shell} \times M_{char\text{-}shell}\,) / NCV_{char\text{-}wood} \qquad (8)$$

3. Results and discussions

3.1 Results of the experimentation of pyrolysis cashew nut shells using an industrial furnace

The study shows that for a mass of shells (M_{shells}) admitted in the pyrolysis furnace, it produces about 17% of cashew shell charcoal (R_{coal}) and about 2% of other residues (ashes, grains of sand, ...). We deduce that the furnace valorizes in the form of gas on average 81% (R_{gas}) of the mass of treated shells. Pyrolysis therefore generates about 98% of combustible organic matter. In addition, the mass of shells used in the process represents on average 11% of the brittle nuts (precooked) and 15% of the shells generated by shelling.

Figures 4 and 5 show the cashew shell charcoal extracted from the pyrolysis furnace and the pyrolysis gas combustion flame.

Figure 4. Image of the cashew shell charcoal from the industrial pyrolysis furnace

Figure 5. Combustion flame of the pyrolysis gas for the boiler supply

3.2 Estimation of potential annual availability of cashew shells

From field studies (visits to processing units) and calculations, we have obtained that cashew nuts shelling generates on average 22% white almonds, 72% shells and 6% skins. In addition, the results of thermochemical studies show that about 15% of the shells generated by the units are used in the transformation process using pyrolysis ovens. Only 85% remains available for energy conversion outside the cashew nuts transformation process (electricity production, other charcoal production, etc.). The synoptic diagram (figure 6) below shows the cashew nut processing process and the current waste management processes by the processing units in Côte d'Ivoire.

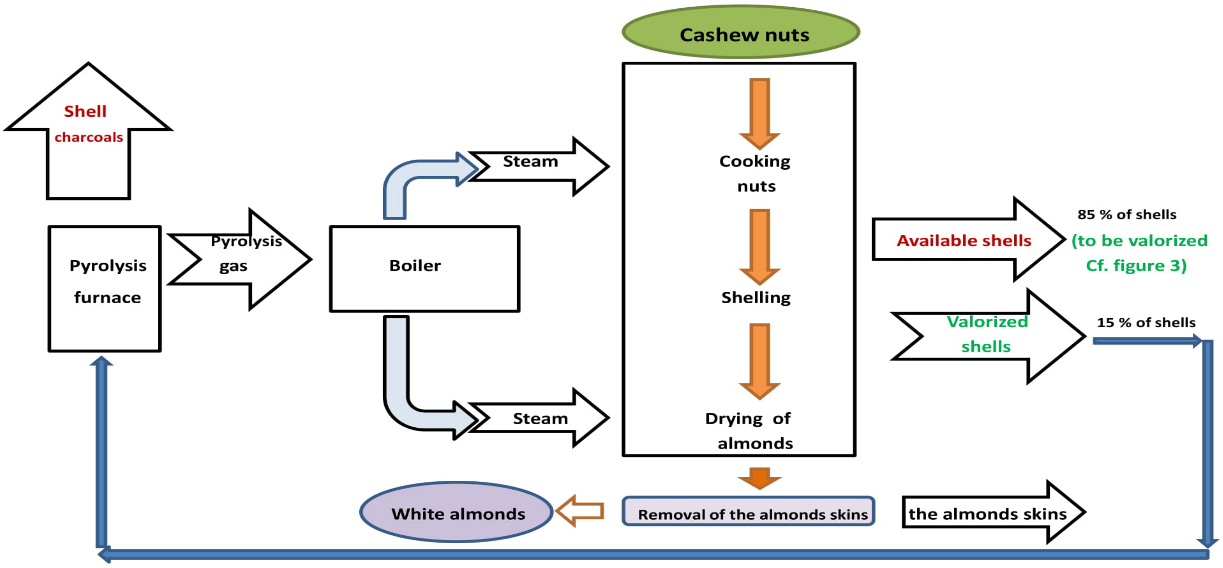

Figure 6. Diagram of the sustainable cashew processing process using industrial pyrolysis furnace

3.3 Results of laboratory analyses and calculation of fuels net caloric value (NCV)

The results of the analysis and calculation of NCV from equations (1) to (3) give the physical-chemical characteristics of the raw cashew nut shells and the different fuels mentioned in Table 1 below.

Table 1. The physical-chemical characteristics of the raw cashew nut shells and the different fuels generated by the pyrolysis.

The different fuels	Moisture content M %	Proximate analysis results in % by mass			Ultimate (elemental) analysis results in % by mass					The different NCV
		Volatile matter content (VM %)	Ash content (A %)	Fixed carbon rate (FC %)	C	H	O	N	S	
Raw cashew nut shells	9	82.2	2.8	15	56.5	7.2	34.2	0.5	0.1	5,217 kcal/kg
Cashew nut shell charcoals	5.86	26.68	6.36	66.97	77.1	3.4	10.7	0.9	0.1	6,799 kcal/kg
Pyrolysis gas	$NCV_{gas\ (app)}$ = 4,317 kcal/kg									

3.4 The national annual energy potential of cashew nut shells available in Côte d'Ivoire (simulation with data for the year 2018)

a) Estimation of the annual energy potential of cashew nut shells for the year 2018

From equations 4 to 6, the results of the pyrolysis study (ratios) and the energy values of the different fuels we derive the following simplified equations 4' and 5':

- $E_{total}\,(toe) = 10^{-7}\,(0.17 \times 6{,}799\ kcal/kg + 0.81 \times 4.317\ kcal/kg) \times M_{shell}$

$$E_{total}\,(toe) = 10^{-7} \times 4\ 652{,}6\ kcal/kg \times M_{shell} \quad (4')$$

- $E_{char\text{-}shell}\,(toe) = 10^{-7}\,(0.17 \times 6{,}799\ kcal/kg) \times M_{shell}$

$$E_{char\text{-}shell}\,(toe) = 10^{-7} \times 1{,}155.83\ kcal/kg \times M_{shell} \quad (5')$$

- $E_{gas\text{-}avail}\,(toe) = 10^{-7}\,(0.81 \times 4{,}317\ kcal/kg) \times (0.85 \times M_{shell})$

$$E_{gas\text{-}avail}\,(toe) = 10^{-7} \times 2{,}972.2545\ kcal/kg) \times M_{shell} \quad (6')$$

Table 2 below contains details of the results of the different energy potentials of the fuels to be generated by pyrolysis, obtained from equations 4' to 6'.

Table 2. Energy potential of fuels to be generated by cashew nut shells pyrolysis (simulation with 2018 data)

The different energy potentials calculated		Total mass of cashew nuts shelled in 2018 : 68,515 tons [4]	
		Mass of cashew nut shells generated in 2018: $M_{shell} = 49{,}331\times 10^3$ kg	
The total energy potential of the shells generated by cashew nut shelling (E_{total})		E_{total} = 22 952 toe	
Energy potentials maximal of fuels available after cashew processing ($E_{fuel\text{-}evail}$)	Energy potential of the shell charcoal generated by the pyrolysis of cashew nut shells	5 702 toe	$E_{fuel\text{-}evail}$ = 20 364 toe
	Energy potential maximal of the available pyrolysis gas (excluding cashew nuts processing energy)	14 662 toe	

The pyrolysis of all cashew nut shells generated in 2018 could enable the production of shell charcoal with an energy potential of 5,702 toe for domestic cooking energy [28] and a quantity of pyrolysis gas with an average energy value of 14,662 toe for decentralized electricity generation [20] in Côte d'Ivoire.

Figure 7 shows the geographical distribution of the annual total energy potential of the fuels to be generated by cashew nut shell pyrolysis for the year 2018, taking into account the quantities of cashew nuts processed by region and districts of Côte d'Ivoire [4].

$E_{Region} = (E_{total} \times M_{shell\text{-}region}) / M_{shell\text{-}total}$

$E_{Region} = (22{,}952 \times M_{shell\text{-}region}) / M_{shell\text{-}total}$

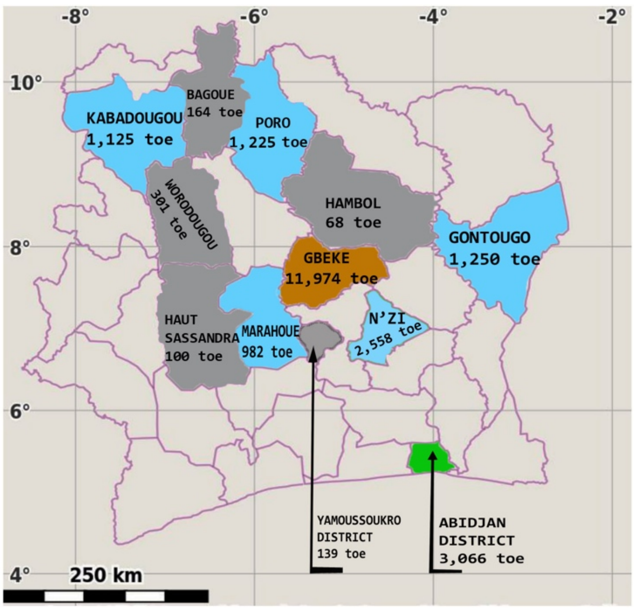

Figure 7. Geographical distribution of the annual energy potential of cashew nut shells available in Côte d'Ivoire, for the year 2018

b) Potential contribution of the integration of cashew nut shell energy recovery into the energy networks in Côte d'Ivoire

✓ *Contribution rate of the integration of pyrolysis gas energy recovery in the electricity mix in Côte d'Ivoire*

The application of equation (7) gives the following result for the year 2018:

E_{elect} (kwh) = $[\eta_{elect} \times (M_{shell} \times 0.81 \times 0.85 \times 4{,}317)] / 860$

E_{elect} (kwh) = $\eta_{elect} \times (49{,}331{,}000 \times 2{,}972.2545) / 860$ (7')

For a conventional biomass thermal power plant with an efficiency of η_{elect} = 35% [20, 26], the conversion of pyrolysis gas into electricity could produce 59,672,675 kWh in 2018.

✓ *Rate of wood charcoal substitutable by cashew nut shell charcoals*

The application of equation (8) gives the following result for the year 2018:

$M_{char\text{-}wood} = (49{,}331 \text{ tons} \times 0.17 \times 6{,}799) / 6{,}211.18$

$M_{char\text{-}wood} = (8{,}386.27 \times 6{,}799) / 6{,}211.18$

$M_{char\text{-}wood} = 9{,}179.94$ tons

The potential for conversion into charcoal of cashew nut shells generated in 2018 is estimated at 8,386.27 tons. This quantity could therefore substitute 9,179.94 tonnes of wood charcoal. The use of cashew shell charcoals could therefore significantly reduce deforestation caused by wood charcoals production.

3.5 Future projection of the availability and energy potential of the integration of cashew nut shell pyrolysis valorization in Côte d'Ivoire

The nominal annual cashew nut shelling capacity of the agro-industrial units installed in Côte d'Ivoire is estimated at 161,600 tons [4], about 2.36 times the quantity of 68,515 tons shelled during the 2018 season. Given the growth in the local processing rate since 2016 [4], we estimate that the cashew shell deposit could increase from 49,331 tons in 2018 to 116,352 tons in the coming years. If pyrolysis recovery of all cashew nut shells is integrated, the annual energy potential of fuels produced in Côte d'Ivoire could increase from 22,952 toe to 54,135 toe with a production capacity of 59.67 to 140.78 GWh of electricity using a conventional biomass power plant with an efficiency of 35% [20, 26] and 8,386.27 to 19,780 tons of shell charcoal.

Table 3 shows the nominal annual energy potential of cashew nut shells, by region and district.

Table 3. Summary table of the nominal energy potentialities of cashew nut shells, by region and district of Côte d'Ivoire

Regions and districts of Côte d'Ivoire	Nominal capacities				
	Qt : Quantity of cashew nuts to be processed, in tons/year	M_{shells}: Mass of the quantity of shells to be generated (valorized), in tons/year (0.72 × Qt)	E_{total}: Energy potential, in toe/year (Cf. equation 4')	E_{elect}: Quantity of electricity to be produced, in GWh/year (Cf. equation 7')	$M_{char-shell}$: Quantity of shell charcoal to be produced, in tons/year (0,17 × M_{shell})
Abıdjan dıstrict	38 000	27 360	12 730	33.01	4 651
Gbéké region	50 300	36 216	16 850	43.81	6 157
Yamoussoukro district	1 300	936	435	1.13	159
N'zi Region	12 000	8 640	4 020	10.45	1 469
Kabadougou region	13 500	9 720	4 522	11.76	1 652
Poro region	16 000	11 520	5 360	13.94	1 958
Sassandra region	5 000	3 600	1 676	4.35	612
Worodougou region	6 000	4 320	2 010	5.22	734
Hambol region	3 500	2 520	1 172	3.04	428
Bagoué region	3 000	2 160	1 005	2.61	367
Marahoué region	3 000	2 160	1 005	2.61	367
Gontougo region	10 000	7 200	3 350	8.71	1 224
National values	161 600 tons/yr	116 352 tons/yr	54 135 toe/yr	140.78 GWh/yr	19 780 tons/yr

Furthermore, taking into account the nominal annual cashew nut shelling capacity of the agro-industrial units installed in Côte d'Ivoire, we deduce that the energy potential of the fuels available after cashew nuts processing (excluding processing energy) could therefore change from 20,364 toe to 48,031 toe per year, starting in 2018. The values of the energy potentials per region or district is obtained by applying equations (5') and (6') by taking the shell masses (M_{shells}) mentioned in Table 3.

Figure 8 below shows the distribution of the annual nominal energy potential by region and district of the fuels available after cashew processing in Côte d'Ivoire.

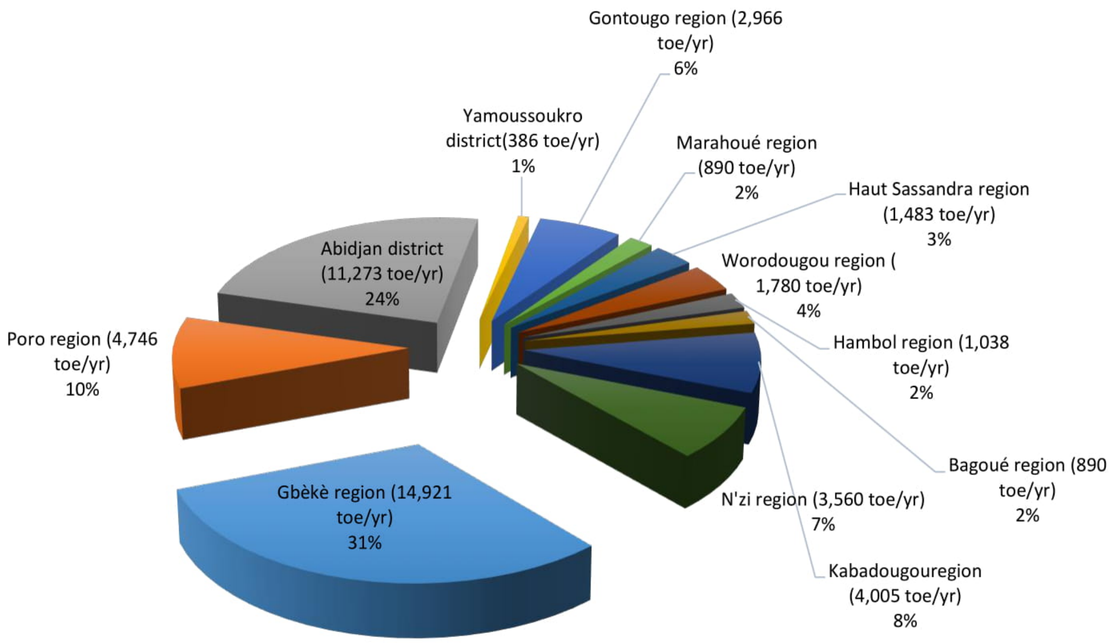

Figure 8. Distribution by region and district of the annual nominal energy potential of fuels available after cashew nut processing in Côte d'Ivoire.

4. Conclusion

The study reveals an increasing annual availability of non-valued cashew nut residues in agro-industrial units. In Côte d'Ivoire, the energy potential of cashew nut shells, estimated at 22,952 toe for the year 2018, will therefore continue to evolve in the coming years. Thus, the sustainable use of all available cashew nut shells as an energy carrier will reduce the increase in charcoal consumption and the use of natural gas for electricity production in Côte d'Ivoire. The development of energy valorization by pyrolysis of cashew nut waste in West Africa will therefore help to increase the percentage of renewable energy in the energy mix and reduce deforestation due to wood charcoal consumption, one of the main causes of local climate change. In addition, it should be noted that the energy recovery by pyrolysis of cashew nut waste in Côte d'Ivoire will enable the various operators of agro-industrial units to work in healthier conditions and avoid polluting the environment by the smoke caused by the combustion of raw shells in landfills and processing units.

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