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RESEARCH ARTICLE

EVALUATION OF THE ENERGY POTENTIAL OF AGRICULTURAL WASTE IN WEST AFRICA FROM THREE BIOMASSES OF INTEREST IN BENIN

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Abstract

The present report deals with the evaluation of abundant Agricultural residues in West Africa based on criteria. These criteria are essentially: the availability of the resource based on a statistical study extended over a period of ten (10) years, the rate of competitive uses of the resource, the critical rate of actual availability and the potential actually available. This study extends the field of knowledge on the physicochemical characteristics of agricultural biomass in countries where the economy is strongly dominated by agriculture. Maize residues come first, followed by cotton, sorghum, rice residues and lastly millet residues. Corn stalks and cobs followed by cotton and millet stems proved to be abundant in the balance of agricultural residues in Benin. This study shows that the biomass resource is more concentrated in the North (Alibori, Atacora, Borgou and Donga), a little less in the center and the South. Similarly, the energy potential of maize residues (stalks and cobs) is very important in the energy balance of the valorization of agricultural biomass and has its source in North Benin where the potential is very remarkable. Added to this is the energy potential of cotton stems. Thus, it is possible to mobilize 458 MW from maize stalks, 205 MW from maize stalks, 6 MW from millet stalks and 62 MW from cotton stalks.

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Introduction:-

Benin is one of the countries in West African sub-region whose economy is strongly dominated by agricultural production. The many efforts made in this area, along with the mechanization of agriculture, have further improved agricultural performance since the 2016-2017 crop year. Also, new crops have emerged with an impressive amount at harvest, generating residues that can be recovered for energy purposes. Benin is also characterized by relatively low energy consumption, with the traditional abusive use of biomass energy used in an unsustainable manner. According to studies carried out by SIE-Benin [1], Benin's total energy consumption is estimated at 5026 ktep in 2017, of which only 95.49 ktep for electric power (1.9 %) compared with 2714.04 ktep in biomass. energy (54 %) and 2166.21 ktep in petroleum products (43.1 %). Indeed, the initial equipment plan submitted by Benin Government to the CIF / SREP program for biomass energy by 2030 is 125 MW. It is in this context that several projects have emerged ... The case of UNDP, which has set itself as its main objective, to promote the production of electricity by the gasification of agricultural residues (biomass), to supply both the main network, only the mini isolated networks. Thus, four (04) different gasification plants for agricultural and forestry biomass are planned respectively in the

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North (Kalalé & Djougou) then in the Center (Dassa & Savalou) for a total production of 4 MW of electrical energy [2], through the "Biomass Electricity Project" for the period 2016-2021. Other forms of energy valorization are observed in Benin (biochemical and thermal recovery), with a view to substituting charcoal / fuelwood with clean energies: in Benin, around 100 biodigesters are installed for cooking and lighting in rural area financed by SNV and ABERME [3]; Another project along the same lines is, for example, the production of green charcoal from agricultural waste (coconut husks, rice balls, maize stalks and stalks, peanut shells, palm waste, sawdust of wood ...) by "ADJS-ONG" on financial support the PMF / FEM and the UNDP [4]. In addition, there are some applications in the field of biofuels, a sector which until recently has been struggling to take off for lack of an appropriate institutional, regulatory and financial framework.

Benin has considerable potential for agricultural and household waste that can be used for energy [5]. Biomass feasibility studies show that global waste management would significantly reduce fossil fuel imports [6]. However, the development of biomass energy sector is hampered by the deficit of characteristic properties of the resource for an efficient valuation.

Indeed, one of the major problems preventing the effective promotion of agricultural biomass is the lack of reliable data on the energy potential of the different agricultural residues available. It is necessary to bring solutions to this problem on scientific level taking into account the availability of these residues (quantity and characteristics for energy uses). This is why we propose to study the "Energy potential of agricultural waste". The present study is based on three types of biomass, from abundant crops in Benin. It is a question of widening the field of knowledge on the different agricultural residues available knowing that the nature of the soil, the culture and the harvest, all depend on the physicochemical characteristics. This study therefore makes it possible to advance knowledge on some of the characteristics of biomass in West Africa in general and Benin in particular. In this context, it is necessary to proceed first to a physicochemical characterization of the material, then to its energetic evaluation according to the identified applications.

Material and Methods:-

Materials:

To determine the parameters listed above, different experimental devices are essential. Thus, all the measurements and experiments were carried out within the BiowooEB laboratory of CIRAD in Montpellier (France). It is essentially:

1. Round glass containers fitted with a lid, cylindrical crucibles and its lid with a mass between 10 and 14 g and a diameter of 25 mm in alumina, fitted with a tight fitting lid. To this, are added porcelain capsules of about 12 mm deep (the diameter of the capsule allows to distribute the amount of sample on 0.15 g/cm^2);
2. PROLABO brand blue-gray oven n° 11445 for drying containers / crucibles / lids;
3. The 'MEMMERT' brand oven which maintains a uniform zone of 105°C for the drying of the material;
4. A precision balance (Denver Instrument) allowing weighings to 0.1mg;
5. Glass desiccants with desiccant silica gel;
6. A 'Nabertherm' electric muffle furnace that can provide a uniform temperature zone;
7. An insulating plate next to the muffle furnace;
8. A Parr 6200 calorimeter, a calorimetric bomb 1108, a calorimetric vessel intended to receive the bomb, immersed in a volume of water of 2 liters, distilled water, ignition wire based platinum and a 0.1°C resolution thermocouple;
9. An elementary analyzer 'VarioMACROcube'.

Unlike stalks and maize cobs that come from natural soil (family culture) without chemical fertilizers, all other agricultural residue samples come from soil enriched with NPK-102020 for millet stems, then NPKSB and urea at 46% N. Selected agricultural biomass samples are from Parakou commune in northern Benin. Unlike stalks that were harvested freshly, millet stems come from a previous crop year (which justifies its availability). The selected biomass samples are as follows:



Figure 1:- Agricultural Residues.

All selected biomass samples were crushed and transformed into 1mm particles of maximum diameter (Figure 2).

Methods:-

The methodology followed is based on selection criteria relating to both biomass availability and the characteristic parameters sought for thermochemical valorization. The first takes into account the abundance of waste via agricultural production and then competitive uses, while the second is based on the physicochemical characteristics of biomass for the evaluation of potential. In this context, the methodology first defines the theoretical potential and the available potential according to competitive uses and moisture content. The evaluation of agricultural waste requires knowledge of the agricultural production of the corresponding crop. Agricultural data are provided by the Directorate of Agricultural Statistics of the Ministry of Agriculture, Livestock and Fisheries (DSA / APRM) in Benin

Based on the average agricultural production potential recorded by each crop by department and on the basis of ratios, the theoretical potential for average gross crop residues by crop and by department is calculated. This potential takes into account all the residues inherent to each crop as shown in Table 1. This study allowed us to select the three flagship crops (in abundant production) as well as the corresponding agricultural residues. This stage of the methodology allows us to determine the average "theoretical potential" based on the selected biomasses.

Table 1:- Biomass energy evaluation method [5].

Types of products	Waste or by-products	Ratio waste/product
Corn	Corn cobs	1
	Leaves and stalks	3
Rice	Straw	1
	Husk	0.25
Millet	Stalks	2
	Epis	0.5
Sorghum	Stalks	2
	Epis	0.5
Cotton	Leaves and stalks	2.7
	Hulls	0.3

Then, from the theoretical potential and on the basis of the moisture content (expert data) and the different competitive uses recorded, the available potential is evaluated. To do this, since there is no data available by department relative to the proportion of competitive uses of agricultural biomass, this study considers the critical biomass availability rates (maximum utilization rate) based on the results of surveys carried out under "Biomass Electricity project". The field survey made it possible to: (i) validate and / or update the data already available on the localities, (ii) estimate the total quantity of waste by agricultural speculation in each of the project communes, highlighting the percentage allocated to soil fertilization and other uses, (iii) to estimate the quantities of agricultural residues available for use in gasification and finally (iv) to identify potential alternative biomasses [7].

The determination of each of the parameters listed above must follow a given standard. The set of standards used in the determination of the physicochemical characteristics of the selected biomasses can be found in the table below. All the characterization results are provided on dry matter.

Table 2:- Different standards used.

Settings searched	Standard
Moisture content (%)	AFNOR NF EN ISO 18134-3
Ash content (%)	NF EN ISO 18122
Content in Volatile Matter (%)	NF EN ISO 18123
Fixed Carbon Content (%)	Norme NF EN ISO 18123
Calorific power (%)	NF EN ISO 18125
Elemental Composition (%)	ASTM D5373 & NF EN ISO 16948

Results:-

An average distribution of agricultural residues from cereal crops in addition to that of cotton (abundant crops / residues available on site) was carried out by department from a statistical study based on ten (10) years of crop years. The result is as follows (Figure 2). The residues affected by each crop are: Maize (flakes, stems and leaves), rice (straw and bales), millet and sorghum (stalks and ears) and cotton (stems & stems, cockles and linters).

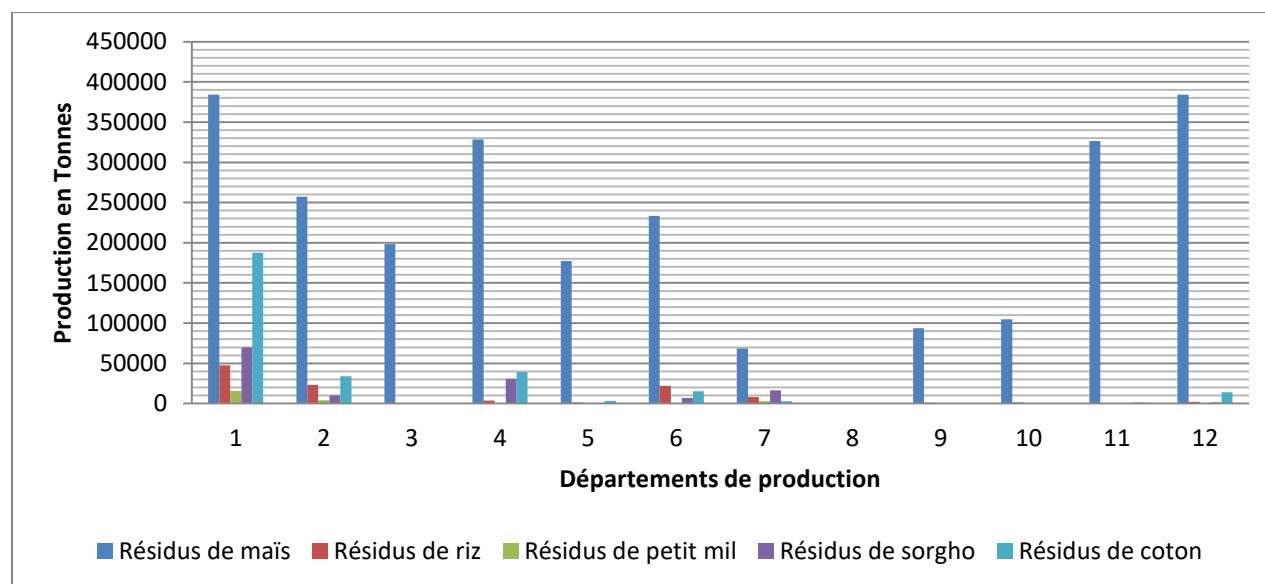
**Figure 2:-** Distribution of Crop Residues Moderately Available by Department (2007-2016) (Adamon, 2019).

Table 3 shows the average annual quantity of agricultural residues by department. Agricultural waste is more concentrated in northern Benin (Alibori, Atacora, and Borgou) and less concentrated in the center and even less in the South. Department (8) that of the coastline does not engage in agriculture. Indeed, it is a department located in southern Benin, fully formed by the economic capital of Benin: Cotonou. Similarly, this table shows that maize residues exist in sufficient quantities: maize is the most consumed cereal in Benin.

Table 3:- Average Total Quantity of Agricultural Residues by Department (Adamon, 2019).

Department	Total annual average amount of gross agricultural residues (Tonne)
Alibori	1 598 161
Atacora	992 166
Atlantique	397 417
Borgou	845 459
Collines	570 172
Couffo	367 331
Donga	203 344
Mono	189 918
Ouémé	212 363
Plateau	658 209
Zou	817 216

Then, we have the cotton waste whose hulls and stems / stems alone confer a significant amount of agricultural residues to this culture which represents the lung of Benin's green economy. Then come the residues of sorghum, rice and millet. From this observation emerge two crops that generate significant amounts of residues: maize and cotton. In addition, the cultivation of millet remains the least abundant and thus causes, to be scrutinized in order to quantify its potential. In addition, it was not possible to collect sorghum stems at the time of the study. In this context, we can mention as pre-selected agricultural residues stalks, stalks and corn leaves, stems, linter and cotton hulls. It must be remembered that maize leaves are very often scattered and spread over the fields for soil fertilization or for livestock feed, while the cotton hulls are used to feed the sheep in the dry season as it is demonstrated in the work of Thys [8]. In addition, some of the cotton stems, like other agricultural residues, are burned in the fields to facilitate the next harvest, reducing the risk of residue-borne diseases after harvest. It follows from this analysis that only stalks and maize cobs on the one hand, and cotton stalks in addition to millet stalks on the other hand, will be studied as selected agricultural biomasses in the rest of this report.

The theoretical potential is nothing more than the amount of gross agricultural residues. It is evaluated from Table 1 and based on biomass selections in addition to sorghum stalks. This potential is presented in Table 4. Table 4 presents two (02) scenarios: one expressing the percentage of selected agricultural residues in relation to the agricultural residues recorded by department and the other the proportion of agricultural residues selected in addition to sorghum stalks in relation to agricultural residues recorded by department. This comparison shows that despite the equally large quantity of sorghum stalks in the agricultural residue balance, they are negligible compared to selected agricultural residues. At the limit, this quota remains the same in departments where sorghum production is non-existent (in the case of the departments of Ouémé and Plateau, for example). Thus, in the following sections, only selected agricultural residues will be the subject of this study.

The technical potential takes into account and the dry biomass and its availability in the field. The different utilization rates considered in this report are taken from the field surveys of the "Biomass Electricity" project, and represent the maximum utilization rates for each residue. In other words, we considered critical availability rates for each agricultural residue [7]. These critical availability rates are respectively for stalks & corn cobs (30%), millet stalks (60%).

Table 4:- Average Quantity of Crop Residues by Department of Selected Biomass (Adamon, 2019).

Department	Average annual total amount of raw agricultural residues (tons)							
	Corn cobs	Corn stalks	Cotton Stalks	Millet Stalks	Sorghum Stalks	Total	Quota ^a (%)	Quota ^b (%)
Alibori	192120	576359	379977	25256	112024	1285736	80.5	73.4
Atacora	128597	385790	175680	25281	60895	776243	78.2	72.1
Atlantique	99204	297612	8	0	0	396824	99.8	98.8
Borgou	164275	492824	79540	1237	49167	787043	93.1	87.3
Collines	116668	350005	30934	8	10969	508584	89.2	87.3
Couffo	88629	265886	6839	0	0	361353	98.4	98.4
Donga	34368	103105	6404	5032	26724	175633	86.4	73.2
Mono	46945	140835	217	0	0	187996	98.9	98.9
Ouémé	52472	157415	4	0	0	209891	98.8	98.8
Plateau	163280	489839	2448	0	0	655566	99.6	99.6
Zou	192097	576291	28400	0	2009	798797	97.7	97.5

Percentage of selected agricultural residues by department taking into account sorghum stalks

Percentage of selected agricultural residues by department without sorghum stalks

On the other hand, for cotton stems, we consider a rate of 50% in view of its high fertilizing potential. In addition, we considered moisture content of 10% (Expert Data) with regard to the type of energy recovery. The availability of the different biomasses selected is presented in the table below (Table 5). It is noted that the available potential is far below the theoretical potential because integrating some parameters inherent in the valorization of biomass.

The physicochemical characteristics of the biomass samples described above are summarized in Tables 6. It can be seen that the selected biomasses have relatively low ash contents. Among the different biomasses studied, only the

cotton stems contain the lowest ash content (2.9%), while the corn stalks record the high ash content (6.51%) and are consistent with the results obtained from Yingquan Chen et al. [9]. According to Luke Williams et al. [10], herbaceous materials such as corn stover have a high ash content of more than 5%. However, the selected agricultural residues generally contain relatively high levels of volatile matter.

In the literature, the key thermochemical property ranges in several biomass feed stocks are [11]: for corn stover FC [15-20%], MV [72-85%] and ash [4-10%] d on the one hand, and for corn cobs FC [17-19%], MV [80-83%] and ash [1-9%] on the other hand. Moreover, it is accepted that biomass contains high levels of VM (ranging from 64 to 98%) compared to fossil coal typically less than 40% according to [12], which are checked against the different results obtained. The results obtained satisfy this criterion with the exception of the VM content of maize cobs (76.52%), which is close to the lower limit of 80%. However, the results obtained from the immediate analysis of the corn stalks are similar to those obtained by Y.J. Lu et al. [13] who obtain respectively (73.44%) in MV, (19.54%) in CF for (6.46%). The same is true for the results obtained from the immediate analysis of the maize cobs: they get respectively (78.17%) in MV, (18.71%) in CF for (3.2%) in ash. As can be seen, the physicochemical characteristics of agricultural biomass differ according to the region of culture [14] [15]. Indeed, Adamon et al. [16]

Table 5:- Average Quantity of Selected Farm Residues Available in Ton (Adamon, 2019).

Department	Average annual quantity of agricultural residues (tons)				
	Corn cobs	Corn stalks	Cotton stalks	Millet stalks	Total
Alibori	51872	155617	170990	13638	392117
Atacora	34721	104163	79056	13652	231592
Atlantique	26785	80355	4	0	107144
Borgou	44354	133062	35793	668	213878
Collines	31500	94501	13920	4	139926
Couffo	23930	71789	3077	0	98796
Donga	9279	27838	2882	2717	42717
Mono	12675	38025	97	0	50798
Ouémé	14167	42502	2	0	56671
Plateau	44086	132257	1101	0	177443
Zou	51866	155598	12780	0	220245

Table 6:- Physicochemical characteristics on dry matter of selected biomasses (Adamon, 2019).

Sample	Characteristics	Corn cobs	Corn stalks	Cotton stalks	Millet stalks
Immediate analysis	Taux de Cendre (%)	6.3	6.51	2.9	3.44
	Taux de Matières Volatiles (%)	76.52	73.89	77.14	77.74
	Taux de carbone fixe (%) ^b	17.18	19.60	19.96	18.82
Ultimate analysis	C (%)	45.1	47.16	46.8	46.9
	H (%)	5.70	5.61	5.88	5.42
	O (%) ^b	48.76	46.78	46.88	47.52
	N (%)	0.48	0.45	0.46	0.18

characterized maize stalks from central Benin and obtained as ash (1.48%) and volatile matter (85.5%), respectively (6.3%) and (76.52%) in this study on samples from northern Benin. Templeton and al. [17] then Eisenbies and al. [18] studied the composition of maize stalks over a large part of the United States, and found that it varies according to the year of harvest, geographical location especially from a structural point of view. In addition, the rate of ash, moisture and carbohydrate depends on the collection conditions [19]. However, the ash content obtained in this study is well within the range (1-8.8%) established by Tao GC et al. for corn cobs [21], as well as ash from corn stalks (2.9% -11.4%). Moreover, the ash content of cotton stems obtained in the present study is very close to that reported by Iyer and al. (3.1%) [22]. The volatiles and ash content of the cotton stems obtained are close to those obtained by Kitani and Hall [23] (73.29% for volatile materials and 21.2% for fixed carbon). In addition, the values obtained from the immediate analysis of millet stems are in line with those obtained by Ansoumane Diedhiou [24] from the millet stalks collected in Senegal: it obtained a fixed carbon content (18.7%).), volatile matter content (78.3%) and the ash rate (5.3%). According to the work of V. Zubkova and al. [25], cereal crop residues contain a

relatively low level of sulfur. In this context, the present study considers that the elemental composition of the different agricultural biomass samples studied is essentially Carbon (C), Hydrogen (H), Oxygen (O) and Nitrogen (N). From the results of Dennis Cardoena and al. [26], sulfur contents are very low and negligible in the order of 0.02% and 0.01% respectively for cotton stalks and maize cobs, with C contents (41.5%), H (6.2%) O (47.5%) for cotton stems, then C (41.4%), H (6%), and O (51.3%) for corn stalks, which are getting closer corresponding levels in this study. In addition, the elemental composition of cotton and corn stalks is closer to that obtained by Shenglei Du and al. [27].

In general, the calorific value of the same agricultural biomass varies according to its region of origin [28] [29]. The lower calorific value values found in this study are in good agreement with those defined by Avcioglu and al. [30]. According to the latter, the PCI of stalks and maize cobs and cotton stems must belong respectively to the predefined intervals of PCI, namely [15.5-18.5], [12.6-18.4] and [14.6-18.2]. In this study, they are 17.4 MJ / Kg (corn cobs), 16.6 MJ / Kg (corn stalks) and 17.1 MJ / Kg (cotton stems) respectively. The table below (Table 7) shows the ICPs of the different samples of biomass studied.

Table 7:- PCI of the different biomass samples studied (Adamon, 2019).

Characteristics	Corn cobs	Corn stalks	Cotton stalks	Millet Stalks
PCI _{anhydride} (MJ / Kg)	16.6	17.4	17.1	17.8

Table 8:- Potential Generation Capacity in MW.

Department	Potential production capacity (MW)				
	Corn cobs	Corn stalks	Cotton stalks	Millet stalks	Total
Alibori	68.9	30.8	33.3	2.8	135.7
Atacora	46.1	20.6	15.4	2.8	84.9
Atlantique	35.6	15.9	-	0	51.5
Borgou	58.9	26.4	7.0	0.1	92.3
Collines	41.8	18.7	2.7	-	63.2
Couffo	31.8	14.2	0.6	0	46.6
Donga	12.3	5.5	0.6	0.6	18.9
Mono	16.8	7.5	-	0	24.4
Ouémé	18.8	8.4	-	0	27.2
Plateau	58.5	26.2	0.2	0	84.9
Zou	68.8	30.8	2.5	0	102.2

:- Insignificant

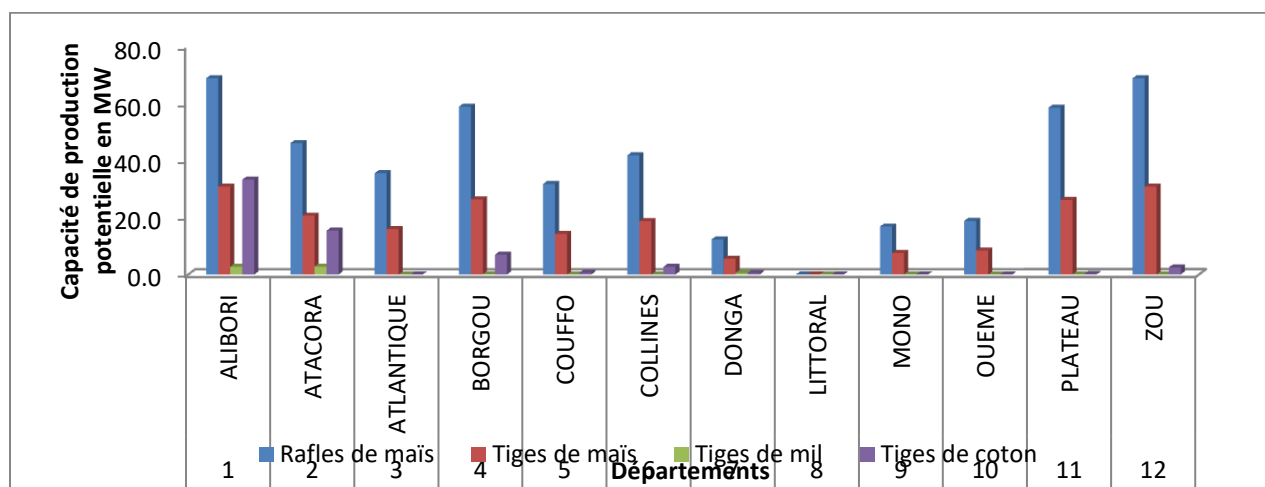


Figure 3:- Potential production capacity from selected agricultural residues.

As illustrated in Figure 3, we can see that most of the energy potential of agricultural biomass is more concentrated in northern Benin (Alibori, Atacora, Borgou and Donga), slightly less in the South (Zou) and the center (Hills).

Similarly, the energy potential of maize residues (stalks and stalks) is very important in the energy balance of the valorization of agricultural biomass and has its source in North Benin where the potential is very remarkable..

Conclusion:-

This study allowed us to select abundant agricultural residues with a major impact on Benin's energy balance. Similarly, it highlighted the spatial distribution of both the availability of biomass and its potential capacity to contribute to the energy mix in Benin. It therefore seems useful to use this form of renewable energy to boost energy production in rural areas according to the energy needs recorded. In addition, project files waiting funding are drawn up on the basis of the diagnosis made and noted in the country's recent political documents.

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