Original Research Article

Estimation of energy potential by anaerobic digestion of agricultural residues in agro-ecological zone 5 in Benin.

ABSTRACT

Aims: Evaluate the available dry matter deposit of crop residues and assimilated as well as its methanogenic and energetic potential in the agro-ecological zone 5, in Benin.
Place and Duration of Study: Rural Engineering Laboratory, National University of Agriculture, Benin, between October 2021 and October 2022.
Methodology: This evaluation was done through a prospective approach based on the Solagro-Indigo method. The potential yield was evaluated using national agricultural statistics and the residue-to-product ratios available in the literature. An exploratory survey was conducted to evaluate the availability of residues in the study area. The methanogenic and energetic potential was determined from the specific bio-methane potentials of each type of residues from previous studies.
Results: This study shows that 71% of the total dry matter produced is not valorized. This important de-posit represents more than 248 million cubic meters of methane and is equivalent to approximately 210 kilo tons of oil equivalent and more than 100% of the total wood energy needs in the region. Additional studies on the optimal conditions for digestion of the main residues identified could promote initiatives for their valorization.
Conclusion: The assessment of agricultural residues potential in the ZAE5 revealed a huge deposit of organic matter that is underpriced and largely abandoned with considerable energy potential. Data are available for each commune and could be used for municipalities development strategies. However, an in-depth study of the optimal methanization conditions and more accurate and precise spatial analyses should be carried out for implementation for energy valorization initiatives.

Keywords: agricultural residue; potential; biogas; energy; Benin

1. INTRODUCTION

With an estimated population of 11.3 million in 2018 (data from National Institute of Statistics and Economic Analysis, 2013), Benin has an overall energy supply of 4,395 ktoe (kilo ton of oil equivalent) per year and annual per capita energy consumption is 0.45 toe/year/capita [1]. Energy self-sufficiency is 62% and remains dominated by wood energy, which accounts for about 97% of the country's self-generation [2]. The average annual consumption of wood (energy) per capita is estimated at 0.7 tons. Agriculture is the country's largest economic sector after the service sector [3]. In 2021 it represented 27% of the GGD and employed more than 70% of the population [4]. Corn, cassava, yams, cotton, soybeans, and rice are among the main products cultivated. The production of these crops generates residues. Agricultural residues include crop residues, which are the aerial parts of plants, apart from economic products, also called noble products, such as cereal grains, tubers, etc. [5]. By extension they also include the residues resulting from the first post-harvest transformations allowing to make the economic products usable or marketable [6], [7]. In contrast to the economic products of crops, there is no systematic and regular monitoring of residues. According to Lacour (2012) this is characteristic of the low interest in residues for a long time and also of the low scale of their valorization in developing countries.

The most important study on the valorization of agricultural residues in Benin is the one that the Ministry of Energy and Water (MEE) carried out with the support of the United Nations Development Program (UNDP) in 2010 [9]. This work aimed at identifying and mapping the potential of different sources of renewable energy. It assessed the ways of their valorization and, has allowed to evaluate, among other sources, agricultural residues potential. The valorization envisaged for agricultural residues in this study is the gasification (except for animal manure) which remains a complex process requiring infrastructures which, on a small scale, are not very efficient.

On the other hand, anaerobic digestion, which is also a way to valorize organic compounds into energy, is a simple and proven process. It transforms organic matter into a biogas, a mixture of methane and carbon dioxide which can be burned to produce energy. It required a basic infrastructure, the digester, which can be implemented on a large but also and small scale [10], [11]. It could thus allow local valorization of the residues. This can thus limit the constraints related to the transport of the residues on long distance, factor which until now would not ease their valorization [12].

However, an anaerobic digestion initiative requires prior knowledge of the quantities of available inputs and their methanogenic potential [13], [14].

This study is part of a general assessment of agricultural residues (crop residues, post-harvest operation residues and animal manure) potential from all crops and animal productions listed in the agricultural statistics. It is carried out in agro-ecological zone 5, which is the largest and most diversified in terms of agricultural production. Most of the crops produced in Benin are found in this zone.

The main objective is to evaluate the importance of the energy potential of available agricultural residues. Specifically, the main residues were identified, their availability and their geographical distribution were assessed on the basis of agricultural statistics and survey results, and finally their methanogenic and energy potential were evaluated.

2. MATERIAL AND METHODS

2.1. Presentation of the study area

In the framework of National Integrated Agricultural Statistics System (SNISA) project, the Ministry of Agriculture, Livestock and Fisheries (MAEP) has defined eight agro-ecological zones classified on the basis of relative homogeneity, considering climatic and agro-pedological parameters, cropping systems, population density, vegetation covers (Figure 1).

Agro-ecological zone 5 (ZAE5) is the largest. It covers an area of 32,163km² and includes 12 communes (Aplahoué, Bantè, Bassila, Dassa, Djidja, Glazoué, Kétou, Ouèssè, Parakou, Savalou, Savè, Tchaourou). It is an area suitable for agriculture and most of the country's crops are grown there. It is watered by the Ouémé River and its major affluents (Zou and

Okpara) [15]. The region is home to the country's two main climate types (subequatorial and tropical) as well as the transition zone.
The main products grown are: cassava, yams, corn, soybeans, peanuts, cotton, rice, cashew nuts, cowpeas, tomatoes, oil palm, okra, peppers, sweet potatoes [16].
According to the latest General Census of Population and Housing (RGPH4), the ZAE5 concentrate a little more than 17% of the population of Benin (INSAE, 2013) and concentrate 20.3% of the agricultural households of the entire country according to the latest agricultural census conducted in 2021, i.e. 187,725 agricultural households [17]. Its energy consumption can be estimated at 800 ktep considering the national average consumption per capita. Similarly, its consumption of wood energy can be estimated at 1.3 million tons per year.

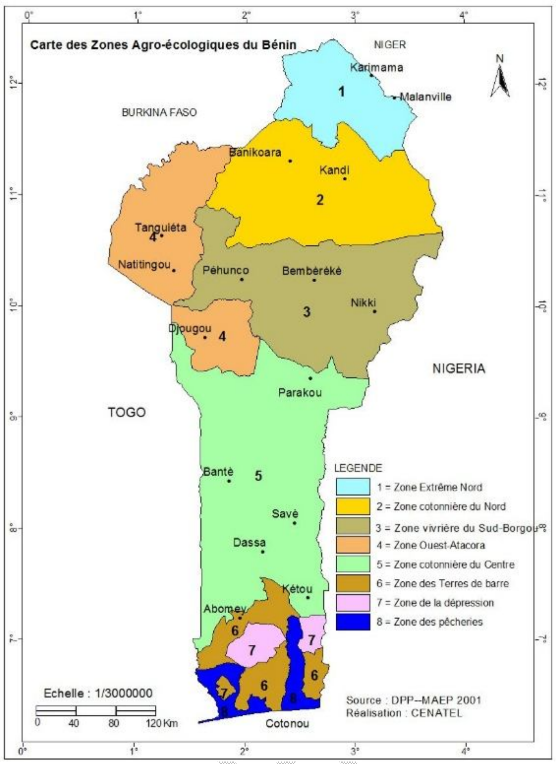

Figure 1. Map of Benin showing the eight agro-ecological zones [9]**.**

2.2. Identification of the most important products

All crops listed in the agricultural statistics of the Directorate of Agricultural Statistics (DSA) were considered first. Production averages per commune and per product were determined from the production data for the years 2018-2019, 2019-2020, 2020-2021. A Hierarchical Clustering on Principal Component (HCPC) was then performed under R 4.2.1 software to determine the different clusters based on the average production and the number of covered area (number of communes) for each product. The purpose of this classification is to consider only the most important products in the following steps of the study. The most important crops are those that are produced in large quantities and in several communes.

2.3. Identification of residues

Three types of residues are considered in this study.

- Crop residues: these include any above ground part of the plants other than the economic product that is not used as new seed.
- Post-harvest residues: these are the residues from post-harvest operations necessary before the conservation or immediate use of the product. These operations essentially

include shelling, hulling, peeling etc. Particularly with cassava, which must be used immediately (a few days only) after harvesting, the peelings are considered here as post-harvest residues.

- Animal excrements: these are the excrements of livestock.

2.4. Estimation of deposits

The methodological approach is based on that of Solagro& Indigo, 2013 [12]. It can be summarized as shown in Figure 2.2.

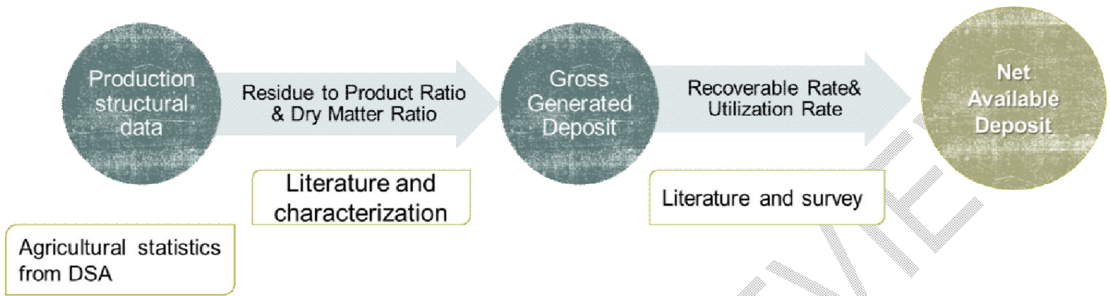

Figure 2. Methodology for the net available deposit assessment

In general, the methodology consists of two levels. At the first one, the Gross Generated Deposit (GGD) is determined from the production structural data of the economic products and the Residue to Product Ratios (RPR). The RPR represent the amount of waste generated by the production of one unit of the economic product [18]. As example, for maize, economic product are maize grains; for cashew, these are cashew nuts. The GGD is directly determined in tons of dry matter with the Dry Matter (DM) rate associated to each RPR. GGD values are then used as input data for the second level. At this level, the current utilization rates of the residues concerned are evaluated in order to determine the availability rate of the residues for a possible further valorization. The availability rates are then applied to the GGD to obtain the Net Available Deposit (NAD) for each residue.

2.4.1. Production structural data

Production structural data are annual crop and livestock statistics obtained from the DSA. The production averages of the last three years of available data (2018-2019, 2019-2020, 2020-2021) were considered.

2.4.2. Residue to Product Ratios (RPR)

The Residue to Product Ratio (RPR) are obtained from literature when available and determined by measurement on samples when not. The RPRs are considered with the corresponding DM rates to avoid the influence of the moisture content which varies according to the harvest time. For each residue the different existing RPR values are listed. Marginal values are excluded as well as those with unspecified DM rates. From the remaining values, the one closest to the median value is chosen.

In the case of a RPR measurement, the crop cut method is used. For each product three crop samples are taken from 25 m² (5 m x 5 m) plots. In the case of plantations, the plots are represented by trees. The weight of the economic products and the different residues are measured. For each type of residue, the RPR is determined by Equation 1.

$$RPR_i = \frac{MR_i}{MP} \qquad (1)$$

With:

RPR_i: Residue to Product Ratio of the residue *i*

MR_i mass of the residue *i*

MP mass of the economic product

Three samples of each residue were then taken to evaluate the dry matter (DM) content. The determination of dry matter content was done by gravimetric analysis with drying at 105°C for 24 hours in an oven. The dry matter content is given by equation 2.

$$DM = \frac{MTF - MR}{MTI - MR} \quad (2)$$

With:
MTF: total final mass of the container and the dried product
MTI: total initial mass of the container and the undried product
MR: mass of the empty container

2.4.3. Determination of the gross generated deposit

For each residue, the gross generated deposit is determined on the basis of the production data of the economic products, the RPR and the DM according to equation 3

$$GGD_i = PA_i \times RPR_i \times DM \quad (3)$$

With:
GGD: *Annual gross residues deposit generated in tons of dry matter*
PA : *Average annual production of the product in tons or in numbers (for livestock)*
RPR: *Residue to product ratio of the residue*
DM: Dry matter rate

2.4.4. Estimation of the recoverable rate

The total amount of residues, especially crop residues, cannot be removed from fields without compromising soil fertility conservation [12], [19]. For crop residues, 15 to 35% of the residues must be left in the field for soil conservation. In the present study a technical abandonment rate of 20% was considered. Thus, the technically recoverable rate (TR) for crop residues is 80%. For post-harvest residues, 100% recoverable rate is considered since the operations are carried out off-farm. As for animal manure, a rate of 50% has been taken into account.

2.4.5. Utilization rate assessment

Crop residues can be used for different purposes. According to FAO (2014) [20], the most important uses of residues in West Africa, are animal feeding, soil fertilization, construction, and fuel.

For each residue, an assessment of the current utilization rate was made by survey with individual interview based on a questionnaire with 207 randomly selected producers in three communes and sixteen different villages of the ZAE5. Areas of high production were mainly targeted. All disposal other than abandonment and burning were considered as current utilizations. For each residue and type of utilization, an average rate is determined with equation 4. The residue utilization rate (*TU) is* then the sum of the rates of the different types of uses (equation 5).

$$Tu_j = \frac{\sum_{i=1}^{n} tu_i}{n} \quad (4)$$

$$TU = \sum_{j=1}^{m} TU_j \quad (5)$$

With:
Tu_j: Rate of a type of use of the residue
n: number of respondents per residue
tu_i: Rate of residue use by type of use and by respondent
TU: Utilization rate of the given residue
m: number of different types of use

2.4.6. Evaluation of the net available deposit (NAD)

The availability rate for each residue is determined by equation 6.

$$TD_i = 100 - TR_i - TU_i \quad (6)$$

With:
TD_i: Availability rate of considered residue in %.
TR_i: Recoverable rate of the residue in %.
TU_i: Current utilization rate of the residue in %.

The net available deposit (NAD) can therefore be determined by equation 7.

$$NAD_i = \frac{GGD_i \times TD_i}{100} \quad (7)$$

2.4.7. Evaluation of biochemical methane and energy potential

The specific biochemical methane potential (BMP) of several residues have been evaluated by different authors [12], [19], [21], [22]. They are expressed as specific dry matter production or specific volatile matter (VS) production.
The BMP values listed for the residues concerned in this study are converted to specific dry matter production by considering an average VS ratio of 0.9 to DM.
The potential bio-methane volume (V_{CH4}) of each type of residue is determined by equation 8.

$$V_{CH4_i} = NAD \times BMP_i \quad (8)$$

V_{CH4} is then converted to tons of oil equivalent (toe). In standard temperature and pressure conditions, 1m^3 of methane is equivalent to 8.47x10^{-4} toe and 5.2x10^{-3} tons of wood [23]. The energy potential E is then obtained by equation 9.

$$E_i = V_{CH4_i} \times 8{,}47 \times 10^{-4} \quad (9)$$

3. RESULTS AND DISCUSSION

3.1 Main agricultural products and their residues in the EAZ5

3.1.1 Crops production

About 34 crops were listed in the DSA database up to 2020. The results of the HCPC shows that the two parameters (average total annual production and covered area) are strongly and positively correlated on axis 1. The analysis shows four clusters (figure 3). Cluster 4, which includes yams and cassava, represents the main products of the area. They are grown in all communes in greater quantities. In contrast, the crops in cluster 1 are produced in few communes and in small proportions. This is the case for cabbage, taro, potatoes, and small millet, among others. Cluster 3 crops are produced in most communes in large quantities, but much less than cluster 4 crops. Cluster 2 products are of average production and coverage.
The crops considered in the rest of this study are those of clusters 3 and 4. The average production per municipality over the last three years of available data for ZAE5 is summarized in table 1.

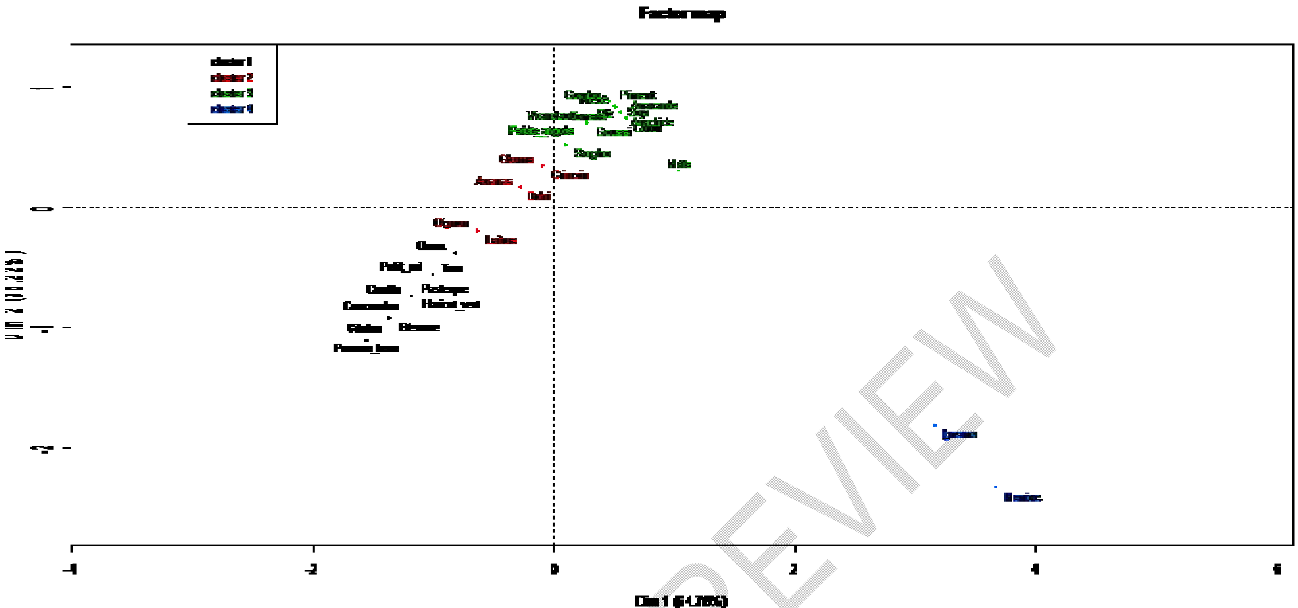

Figure 3. Factor map of the crop's HCPC

Table 1. Most important crops selected for the study.

Products	Average annual production (tons)	Number of municipalities
Cassava	1 812 822	12
Yam	1 523 378	12
Corn	331 493	12
Cotton	86 790	12
Peanut	62 331	12
Cashew nuts	61 513	12
Rice	60 715	12
Soybeans	56 594	12
Cowpea	34 104	12
Tomato	32 392	12
Pepper	9 929	12
Okra	9 866	12
Sweet potato	7 242	11
Sorghum	7 176	10
Bambara nut	3 443	11
Pumpkin seeds	3 106	11
Pigeon peas	2 086	11

Source: DAS 2021

3.1.2. Animal production

ZAE5 accounts for about 14% of national production in cattle, goats, and sheep, 18% in pigs, and more than 30% in poultry, according to data from the Directorate of Animal Production for the years 2013, 2014, and 2016. Except for Parakou, livestock numbers are relatively high in the rest of the area (Table 2). However, Tchaourou and Djidja dominate in cattle and pig breeding respectively.

Table 2.Livestock production in ZAE5.

COMMUNES	Cattle	Goats	Sheep	Pigs	Poultry
APLAHOUE	7 141	6 205	7 920	6 794	3 139
BANTE	16 339	3 399	1 398	1 792	1 278
BASSILA	36 837	2 606	3 668	1 980	1 679
DASSA ZOUME	29 515	3 988	2 470	3 474	1 616
DJIDJA	35 831	4 040	5 837	12 280	3 090
GLAZOUE	24 179	4 485	3 145	4 197	2 360
KETOU	7 962	2 621	1 233	4 006	1 114
OUESSE	28 144	2 031	2 073	4 939	1 928
PARAKOU	8 760	933	766	927	569
SAVALOU	43 228	9 545	4 769	4 456	3 259
SAVE	26 208	2 433	1 312	2 469	1 071
TCHAOUROU	87 724	4 018	4 823	3 088	1 743

Source: DSA 2021

3.2 Residues identified and their RPR

The residues, their RPR and their DM are compiled in table 3. RPR values exist for most residues. Only cashew apples and cassava peelings were the subject of characterization studies.

RPRs vary from one waste to another. The dry matter content also varies. However, apart from cashew apples and cassava peelings, crop and post-harvest residues are dry residues with DM range between 82 and 98%. Cattle and pig manure on the one hand, and goat, sheep and poultry manure on the other, have similar dry matter contents, but with RPRs that vary considerably.

Table 3.RPR and DM of residues.

Types of residues	Products	Residue	RPR	DM (%)	References
	Cashew nuts	Cashew apple	11,50	13	c
	Peanut	Peanut straw	2,30	85	a
	Cotton	Cotton stalk	2,76	88	a
		Corn straw	2,00	85	a
Crop residues	Corn	Corn cobs	0,27	92	a
		Corn husk	0,20	89	a
	Cassava	Cassava stalk	0,06	85	a
	Cowpea	Cowpea straw	2,90	85	a
	Rice	Rice straw	1,76	87	a

	Soybeans	Soybean straw	3,50	85	a
	Sorghum	Sorghum straw	1,25	85	a
	Bambara nut	Bambara nut straw	2,30	85	a
Post-harvest residue	Peanut	Peanut shells	0,48	92	a
	Cassava	Cassava peelings	0,17	27	c
	Rice	Rice husk	0,27	98	a
Feces	Cattle	Cattle manure	4,38	12	b
	Goats	Goat manure	0,55	25	b
	Sheep	Sheep manure	0,44	25	b
	Pigs	Pig manure	1,31	11	b
	Poultry	Poultry manure	0,01	25	b

a: [18] *b:* [19] *c: study*

3.3. Gross Generated Deposit

The residue assessment shows that over 2 million tons of dry matter from agricultural residues are produced in the ZAE5. Corn straw is the most abundant residue (table 4), accounting for 28% of the total. The commune of Kétou concentrates the most residues (figure 4).

Table 4. Gross generated residues deposit.

Residues	**GGD in tons of DM**
Corn Straw	563 539
Cotton stalk	210 414
Cattle manure	184 942
Soybean straw	168 368
Peanut hulls	121 857
Cassava stalk	96 614
Rice straw	93 118
Cashew apple	91 962
Cowpea hulls	84 067
Corn cobs	83 683
Cassava peelings	83 209
Goat manure	63 378
Corn husks	58 933
Sheep manure	43 157
Peanut shells	27 294
Rice husks	15 827
Pig manure	14 569
Sorghum straw	7 624
Bambara nut straw	6 730
Poultry manure	4 170
TOTAL	2 023 454

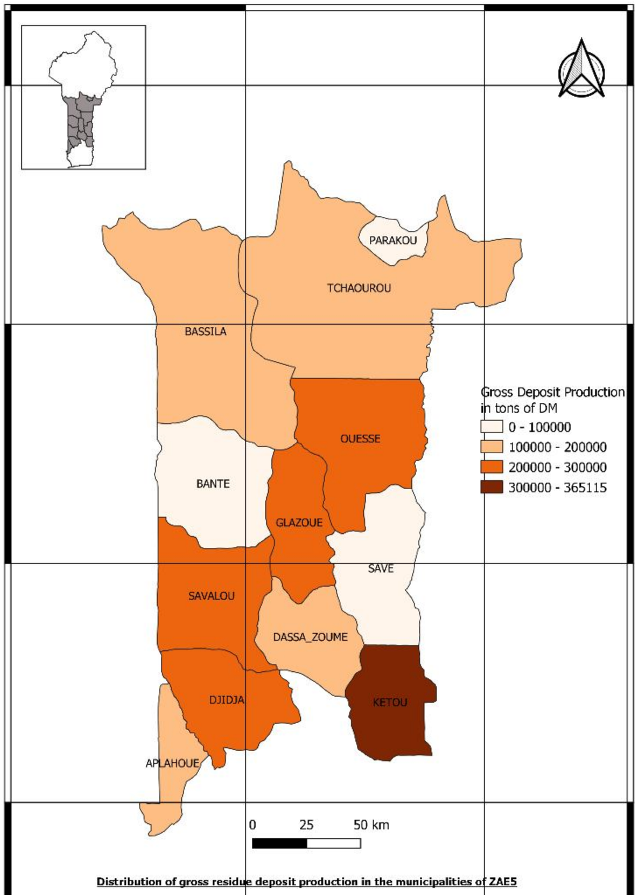

Figure 4. Distribution of gross generated residues deposit in ZAE5

3.4. Net available deposit

3.4.1. Actual utilization of residues

Average utilization rates are summarized in table 5. Apart from cassava peels and stalks, which are used to a considerable extent (67% and 70% respectively), the other residues are not used or used to a low extent. The standard deviations are relatively high in the cases of low utilization, showing that these are isolated cases of utilization.

Table 5. Average residues utilization rate

Types of residues	Residue	Number of respondents	Average utilization rate %.	Standard deviation
	Peanut straw	102	1,0	9,9
	Cowpea straw	101	11,0	30,7
Harvest	Bambara nut straw	28	-	-
	Rice straw	77	1,6	8,4
	Soybean straw	127	2,1	11,4

	Sorghum straw	15	6,7	25,8
	Corn Straw	76	-	-
	Cashew apple	92	1,4	7,9
	Corn cobs	76	1,2	7,7
	Corn husk	76	-	-
	Cotton stalk	33	-	-
	Cassava stalk	78	70,1	26,0
	Rice husk	4	25,0	50,0
Post-harvest	Peanut shells	7	-	-
	Cassava peelings	9	66,7	34,6
	Cattle manure	3	6,7	11,5
	Goat manure	29	-	-
Feces	Sheep manure	22	-	-
	Pig manure	7	-	-
	Poultry manure	33	-	-

3.4.2. Types of use

More than 75% of the residues are burned or abandoned, except for cassava stalks and peels. After cassava peels and stalks, sorghum straw and rice husks are the most valuable residues. There are three main types of valorization of the identified residues.

- Animal feedings

Several residues are used by producers for livestock feeding. Cassava peelings are used mainly for livestock feeding as shown in table 6. Sorghum straw and rice husks are also used. Other residues are also used, but to a lesser extent. These include cowpea and peanut straw, cassava stalks, soybean straw, and cashew apples.

- Fuel

Only corn cobs are used as fuel at a low rate of 2.25%.

- Sales and others

About 70% of cassava stalks are sold or reused by producers as new seeds. About 2% of rice and soybean straws are used as mulch for yam mounds. A part of the ash from burned soybean straws is also used to make "koto" soap. The 0.3% of cashew apples that are recovered are processed into juice.

Table 6.Proportion of residues by disposal options.

Residue	Proportions in % by disposal options						
	Feeding	Compost	Fuel	Sale	Other	Abandoned	Burned
Peanut straw	0,97	-	-	-	-	45,63	53,40
Cowpea straw	11,10	-	-	-	-	48,90	40,00
Bambara nut straw	-	-	-	-	-	35,71	64,29
Rice straw	-	-	-	-	1,62	46,95	51,43
Soybean straw	1,06	-	-	-	1,05	44,19	53,70
Sorghum straw	6,67	-	-	-	-	46,67	46,67

Cashew apple	-	-	-	-	1,10	98,90	-
Corn cobs	-	-	1,22	-	-	90,68	8,11
Corn husk	-	-	-	-	-	91,78	8,22
Cotton stalk	-	-	-	-	-	12,12	87,88
Cassava stalk	3,29	-	-	4,04	63,22	19,28	10,17
Corn straw	-	-	-	-	-	93,24	6,76
Cattle manure	-	-	-	-	6,67	93,33	-
Goat manure	-	-	-	-	-	100,00	-
Sheep manure	-	-	-	-	-	100,00	-
Pig manure	-	-	-	-	-	100,00	-
Poultry manure	-	-	-	-	-	96,97	3,03
Rice husk	25,00	-	-	-	-	25,00	50,00
Peanut shells	-	-	-	-	-	28,57	71,43
Cassava peelings	66,67	-	-	-	-	33,33	-

3.4.3. Net Available residues deposit

The majority of generated residues is hardly used. They remain significantly available despite considering the technical abandonment rate in the field. The availability rates by residue range from 10 to 100% as shown in table 7.

Of the 2 million tons of DM of residues produced, 1.44 million remain available taking into account soil conservation and current uses. Corn straw is the most available residue and represents about 30% of the total amount of residue.

The available residue deposit in the EAZ5 appears to be important in comparison to previous results obtained by other authors. For example, Haiti, the estimated gross potential of crop residues and dung is 2.7 million tons of DM for the whole country [22].

Table 7.Availability rate and net available deposit of residues.

Residue	Recovery rate %.	Utilization rate %	Availability rate %	NAD tons of DM	Proportion %
Peanut straw	80,0	1,0	79,0	96 302	6,7
Cowpea straw	80,0	11,0	69,0	58 014	4,0
Bambara nut straw	80,0	-	80,0	5 384	0,4
Rice straw	80,0	1,6	78,4	72 983	5,1
Soybean straw	80,0	2,1	77,9	131 141	9,1
Sorghum straw	80,0	6,7	73,3	5 591	0,4
Corn Straw	80,0	-	80,0	450 831	31,3
Cashew apple	100,0	1,4	98,6	90 662	6,3
Corn cobs	100,0	1,2	98,8	82 692	5,7
Corn husk	100,0	-	100,0	58 933	4,1
Cotton stalk	80,0	-	80,0	168 331	11,7
Cassava stalk	80,0	70,2	9,8	9 513	0,7
Rice husk	100,0	25,0	75,0	11 870	0,8
Peanut shells	100,0	-	100,0	27 294	1,9

Cassava peelings	100,0	66,7	33,3	27 736	1,9
Cattle manure	50,0	6,7	43,3	80 141	5,6
Goat manure	50,0	-	50,0	31 689	2,2
Sheep manure	50,0	-	50,0	21 578	1,5
Pig manure	50,0	-	50,0	7 285	0,5
Poultry manure	50,0	-	50,0	2 085	0,1
TOTAL	-	-	-	1 440 057	100,0

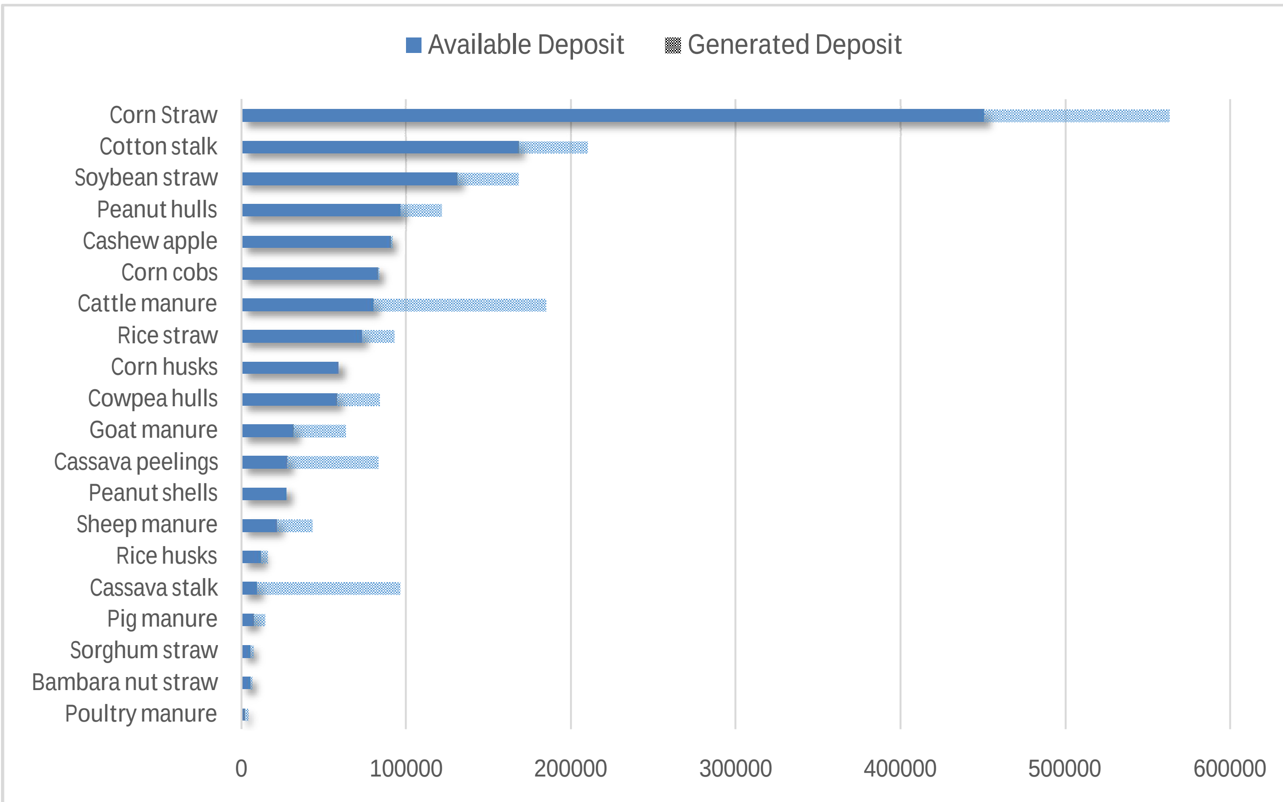

Figure 5. Net Available Deposit vs. Gross Generated Deposit

3.5 Estimation of the methane potential and its energy equivalence

Table 7 shows different specific values of BMP in terms of dry matter, methane potential and the corresponding energy value. The available residue deposit represents a total of $261x10^6$ m^3 of methane. This significant energy potential is equivalent to 210 ktoe and 1.3 million tons of wood. The methane potential of corn straw is the most important and represents 30% of the total potential. Kétou remains the commune with the highest potential with more than 45.10^6 m^3 of methane that can be produced per year. Corn residues represent about 80% of its total potential.

In all municipalities, the energy potential of crop residues is the most important and represents 80 to 95%, except in Tchaourou where 32% of the potential comes from dung (figure 5).

Compared to the estimated energy consumption for ZAE5, potential energy of the available residues represents more than 25% of the total estimated household consumption of the ZAE5 and more than 100% of the wood energy needs. Moreover, according to UEMOA [24], energy consumption is relatively low in rural communities, especially for electricity and transportation. So the available residue potential could cover more than 25% of total estimated consumption, since the need was estimated based on national average energy consumption per capita, due to lack of more precise data.

Table 7.Methanogenic and energy potential of available residues.

Residue	BMP m^3 CH4/tMS	References	Bio-methane potential Nm^3 /year	Energy potential toe/year	Proportion % of total
Soybean straw	127	a	14 989 445	12 696	6,0
Cashew apple	64	b	5 222 157	4 423	2,1
Peanut straw	242	c	20 974 634	17 766	8,4
Cowpea straw	123	c	6 422 175	5 440	2,6
Bambara nut straw	242	c	1 172 689	993	0,5
Rice straw	242	c	15 895 686	13 464	6,4
Sorghum straw	134	c	674 303	571	0,3
Corn Straw	189	c	76 686 358	64 953	30,9
Corn cobs	189	c	14 065 949	11 914	5,7
Corn husk	238	d	14 026 030	11 880	5,6
Cotton stalk	225	d	37 874 456	32 080	15,2
Cassava stalk	192	d	1 826 457	1 547	0,7
Rice husk	189	c	2 019 104	1 710	0,8
Peanut shells	189	c	4 642 671	3 932	1,9
Cassava peelings	267	c	6 665 002	5 645	2,7
Cattle manure	168	e	13 463 765	11 404	5,4
Goat manure	184	e	5 830 806	4 939	2,3
Sheep manure	192	e	4 143 053	3 509	1,7
Pig manure	192	e	1 398 657	1 185	0,6
Poultry manure	240	e	500 370	424	0,2
TOTAL			248 493 766	210 474	100,0

a : [25] b : [21] c : [22] d : [19] e : [12]

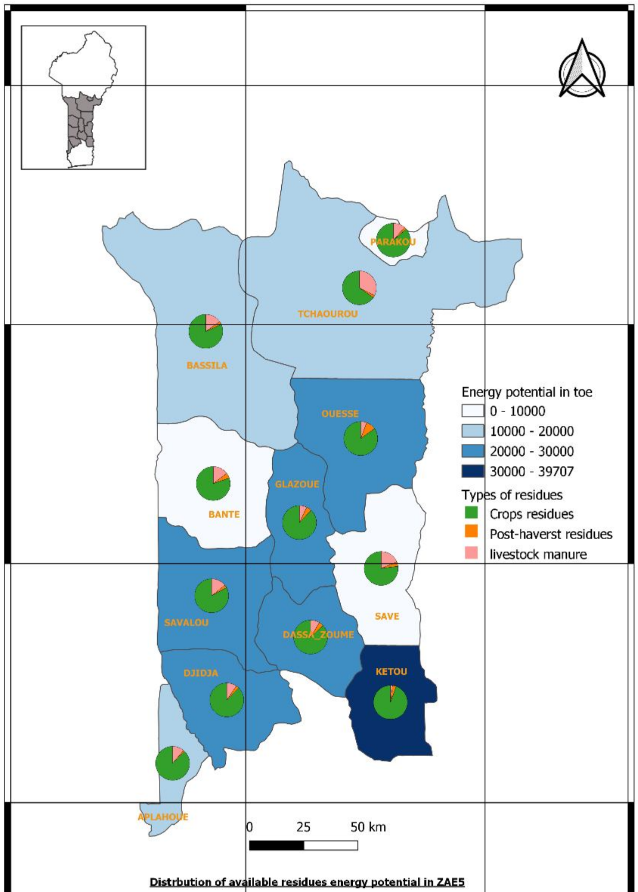

Figure 6. Distribution of available residue energy potential in ZAE5

4. CONCLUSION

The assessment of agricultural residues potential in the ZAE5 revealed a huge deposit of organic matter that is underpriced and largely abandoned. The recoverable energy potential of these residues is important and can cover a great part of the total energy needs of the region through anaerobic digestion. Kétou is the commune with the highest potential and corn straw is the most abundant. Data are available for each commune and could be used for municipalities development strategies. However, the actual production of bio-methane from these residues may vary depending on the digestion conditions. An in-depth study of the optimal methanization conditions for the various residues could enable energy valorization initiatives. However, more accurate and precise spatial analyses should be carried out for implementation of these projects.

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Table 8. Methanogenic and energy potential of available residues.

Residue	**BMP m3 CH4/tMS**	**References**	**Bio-methane potential Nm^3 /year**	**Energy potential toe/year**	**Proportion % of total**
Corn Straw	189	c	76,686,358	64,953	30.9
Cotton stalk	225	d	37,874,456	32,080	15.2
Peanut straw	242	c	20,974,634	17,766	8.4
Rice straw	242	c	15,895,686	13,464	6.4
Soybean straw	127	a	14,989,445	12,696	6
Corn cobs	189	c	14,065,949	11,914	5.7
Corn husk	238	d	14,026,030	11,880	5.6
Cattle manure	168	e	13,463,765	11,404	5.4
Cassava peelings	267	c	6,665,002	5,645	2.7
Cowpea straw	123	c	6,422,175	5,440	2.6
Goat manure	184	e	5,830,806	4,939	2.3
Cashew apple	64	b	5,222,157	4,423	2.1
Peanut shells	189	c	4,642,671	3,932	1.9
Sheep manure	192	e	4,143,053	3,509	1.7
Rice husk	189	c	2,019,104	1,710	0.8
Cassava stalk	192	d	1,826,457	1,547	0.7
Pig manure	192	e	1,398,657	1,185	0.6
Bambara nut straw	242	c	1,172,689	993	0.5
Sorghum straw	134	c	674,303	571	0.3
Poultry manure	240	e	500,370	424	0.2
TOTAL			248,493,766	210,474	100