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BIOGAS POTENTIAL OF THE AGRO-PASTORAL RESIDUES AND HUMAN EXCREMENT IN THE COMOÉ RIVER CATCHMENT (CÔTE D'IVOIRE)

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ABSTRACT
Human dejections and agro-pastoral residues biogas potentials of the Comoé river catchment (CRC) were evaluated using agricultural and population statistics, and the indices of residues biogas productivity. The CRC contains an annual biogas volume of $318x10^6m^3$. This energy resource is by far higher than the energy needs of rural population in Côte d'Ivoire. But this resource is unequally distributed in the CRC localities. Ferkessédougou department contains the maximum potential ($172.7x10^6m^3$) of biogas. The agricultural residues among the others wastes contained the highest biogas potential ($124.8x10^6m^3$). The complexity of biogas production from agricultural solid organic residues makes these substrates inappropriate to household exploitation. In the other hand, centralized unit can be installed in Ferkessédougou and Abengourou to produce biogas from these residues in the aforementioned localities. Small decentralized units could be established in the localities containing livestock waste. Biogas production using agro-pastoral organics residues must be preceded by sensitizing of populations, in order to reduce their traditional utilisation habit and to fight against taboos.

Keywords: Agriculture, biogas, population, residues, river catchment.

INTRODUCTION
The question relating to energy importance goes up at man origins and it is not utopian of saying that development stops where the energy resources are rare. Because energy gives access to education, information, improves living conditions of rural communities. Energy also contributes to poverty reduction. Moreover, the importance of the access to energy, as an essential good, was a central topic at the international on sustainable development at Johannesburg in 2002. The link between energy and poverty was highlighted in chapter 13 of the world prospects for energy (IEA, 2002). Energy crisis of these last decades, characterized by fossil energies prices increase, finished convincing of the need for seeking alternative energies (Chynoweth, Owens, & Legrand, 2001; Wauthelet, 2001). At the same time, biomass remains the principal energy source of 2.4 billion populations in developing countries (IEA, 2000). In these countries, biomass contributes for more than 90% of energies used, of which two thirds are used to satisfy the domestic needs (FAO, 2003). However the utilisation of this energy source poses major environmental problems (soil degradation, deforestation, desertification, reduction of CO_2 sink), health (pulmonary diseases and eyes) and women occupation (91%) (Mehretu & Mutambira, 1992; WHO, 2000). Moreover, the availability of wood becomes rare in certain zones because of their overexploitation, which obliges women and children to cover long distances for their collection. Biogas is a source of

energy whose production may be done with various organic wastes; human excrements, agricultural and livestock waste (Cho, Park, & Chang, 1995; Gowga et al., 1995; Kivaisi & Rubindamayugi, 1996; Moller, Sommer, & Ahring, 2004; Nabinta, Yahaya, & Olajide, 2007; Zhang & Zhang, 1999). Conversion of these wastes to biogas could be the best management way to manage them. In addition, biogas technology is flexible and implementation easier and reactor units can be decentralized in rural area (Chanakya, Rajabapaiah, & Modak, 2004). But its implementation in the most of developing countries, such as Côte d'Ivoire, is still modest. This situation is due to the lack of incentive and dissemination policies of biogas. Biogas vulgarisation may start with a best evaluation of the stock of substrates that will be used (FAO, 1998; Kumar et al., 2002; Nelson et al., 2004). Côte d'Ivoire economics are based upon agriculture and related activities. As a consequence there is a massive production of agro-pastoral residues. The generated wastes could be converted to biogas that could contribute to rural populations living condition improvement (Chanakya et al., 2004; PNUD, 2003), reduction of greenhouse gas emissions and limitation of deforestation. For example, the digestion of human excreta contributes to the destruction of pathogenic organisms (Billaud & Varagnat, 1983) and at the same time produce biogas.

The aims of this research were (i) to quantify the volume of biogas which may be produced from agro-pastoral wastes and human dejections in each locality within the river Comoé catchment area and (ii) to analyze the implementation options of biogas units.

MATERIAL AND METHODS

Study area

The comoé river catchment (CRC) is located at the East of Côte d'Ivoire between 935 and 1 105 of Northern latitude and 330 and 530 of longitude western and left again between Côte d'Ivoire, Burkina Faso and Ghana (Girard, Sircoulon, & Touchebeuf, 1971). It is limited to the West by the basins of Bandana and Agneby and in the East by those of Volta Noire and Bia. Comoé has an overall length of 1 160 km including 900 km in Côte d'Ivoire and a surface of 57 300 km². It drains partly or entirely 8 of the 19 administrative regions of Côte d'Ivoire (Figure 1). The CRC contains elevated rural populations which exert significant pressure on the forests because of its exploitation for energy resource.

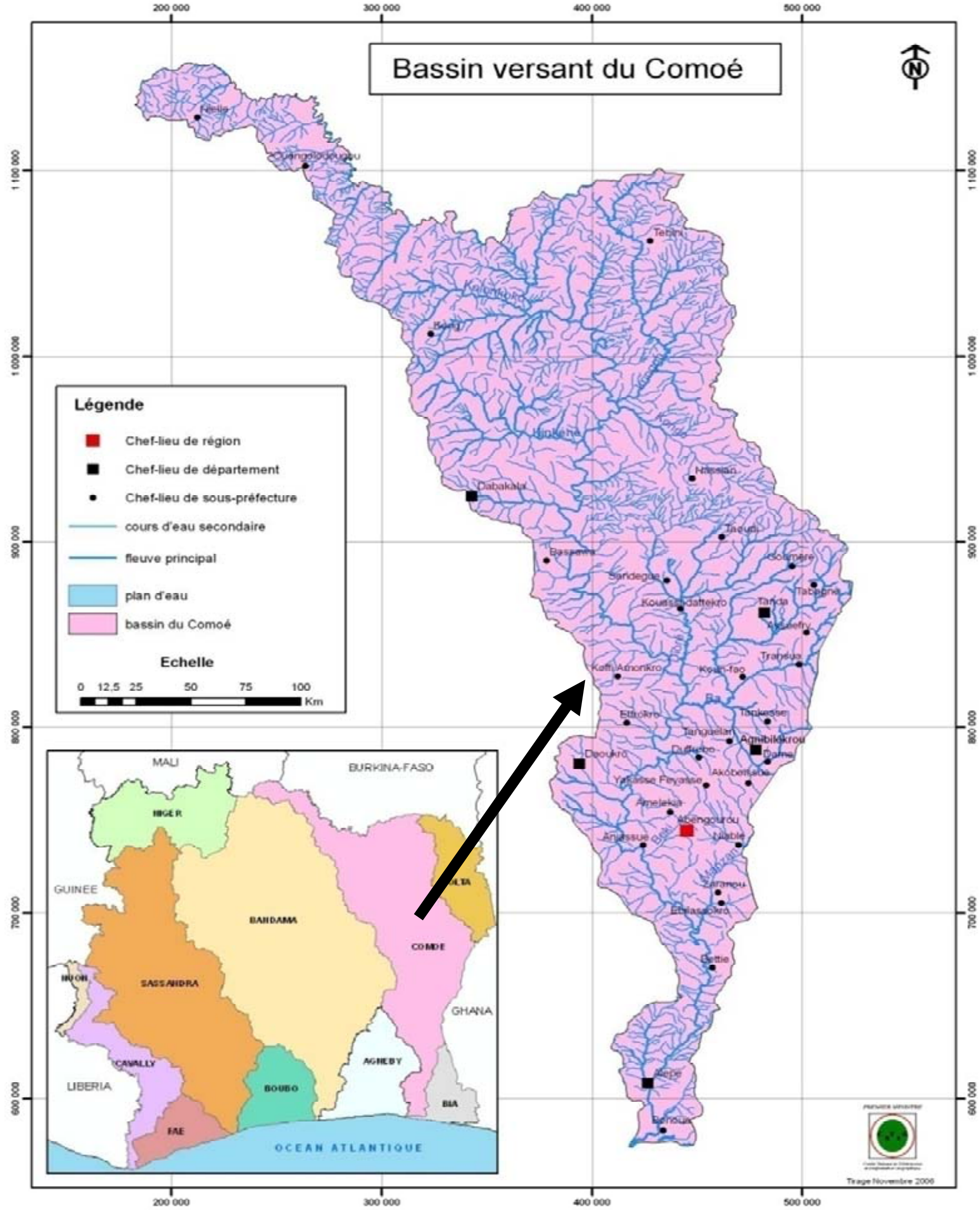

Figure 1: Localization of the Comoé river catchment (Côte d'Ivoire).

Data

The data on agriculture and livestock wastes were obtained from the agriculture and livestock statistics. The statistics on population was obtained with the Nation Institute of Statistic (INS, 2000). The statistics on the poultry in the CRC were not available. However, these data do not influence significantly the results in the whole CRC because the density of poultry is above 3 000 individuals per km^2 only in the departments of Bondoukou and Dabakala (FAO, 2005).

Biogas potential of waste

The exploitation of the data has consisted in evaluating firstly the waste generated by the population, agriculture and livestock.biogas volumes of the wastes using, wastes masses and their biogas productivity indices.

Human excrements

The potential production of biogas of human excrements (P_{Hu}) in each locality of the CRC was estimated by the relation (1).P_{Hu} (m^3) = POP_{Hu} x RJ_{Hu} x Ip x 365 (1)

POP_{Hu}: Population number of the locality,

RJ_{Hu}: Day labourer production of excrements (kg/person),

Ip: Index of productivity,

365: Days number in one year.

The estimations were conducted using RJ_{Hu} = 0.4 kg/person and Ip = 0.028 m^3/(kg of excrements) (Nabinta et al., 2007).

*Animal manure*The potential production of biogas from the dejections of livestock was calculated following relation (2). The QMO and Ip values of the animals are presented in table 1.

P_{An} (m^3) = POP_{An} x QMO x Ip x 365 (2)

POP_{An}: Number of animals by type,

QMO: Organic day labourer quantity of matter (kg/animal),

Ip: Index of productivity,

365: Days number in one year.

Table 1: QMO and Ip mean values of the animals (Villaud & Varagnat, 1983).

	Cattle (250 - 400 kg)	Ovine (45 kg)	Goat (45 kg)	Pigs (30 - 80 kg)
QMO (kg/head)	2	0.6	0.6	0.32
Ip (m^3/kg of OM)	0.38	0.3	0.3	0.56

Agricultural residues

The annual potential production of biogas of the agriculture residues was estimated starting with the quantity of dry matters (QMS) of the aforesaid residues (Equation 3).

QMS = m x Cres x Cms (3)

The biogas potential (P_{Ag}) of the agricultural solid residues was calculated using relation 4.

P_{Ag} = QMS x Ip (4)

The relations (3) and (4) combined give the relation (5):

P_{Ag} = (m x Cres x Cms) x Ip (5)

m: Mass of agricultural production (tons), Cres: Coefficient expressing the quantity of residues generated according to the agricultural production; Cms: Proportion of dry matters contained in the residues,

I_P: Index of productivity.

Cms, Cres and IP values used are presented in table 2.

Table 2: Cres, Cms and Ip values (Billaud & Varagnat, 1983; FAO, 1998).

Wastes typology by culture		Values and references		
		FAO (1998)		Billaud & Varagnat (1983)
Cultures	Wastes	Cres	Cms	Ip (m^3/tons of MS)
Rice	straw	1.757	0.87	360
	husk	0.267	0.98	300
Maize	husk	0.2	0.89	300
	cob	0.273	0.93	300
	Stalk	2	0.85	295
Palm oil	Empty bunche	0.23	0.5	300
	Fiber	0.14	0.6	300
	Shell	0.065	0.9	300
Cocoa	pods	1	0.85	300
Coffee	Shell	2.1	0.85	300
Cotton	Stalk	2.755	0.88	300
Manioc	Stalk	0.062	0.85	300
	Peel	0.025	0.5	300
Mil	Stalk	1.75	0.85	300
Sorghum	Stalk	1.25	0.85	278
Coconut	Shell	0.12	0.913	300
	Coir	0.419	0.897	300
Groundnut	Shell	0.477	0.918	300
	Straw	2.3	0.85	298

Calorific biogas values

The low calorific value (LCV) of the biogas was used to determine the equivalent energy of the biogas volume estimated.biogas containing 50 and 70% of methane, LCV varies respectively from 4.5 to 6.7 KWh/m^3.

Level of agricultural residues valorisation

Its determination consisted in carrying out an information retrieval and a visit of field to determine the valorisation modes (composting, biomethanisation, in situ incineration, combustion for the domestic needs, and transformation into charcoal) of the wastes in the CRC.

RESULTS AND DISCUSSION

Results

Figure 2 presents the volume of biogas estimated from human excrement in the localities of CRC. The maximum biogas volume was obtained in Abengourou (0.7 x 10^6 m^3) and this locality is followed by that Agnibilékro (0.2 x 10^6 m^3).Bouna and Alépé localities produce the lowest volumes of biogas respectively 0.01 x 10^6 and 0.02 x 10^6 m^3 from human excrement.

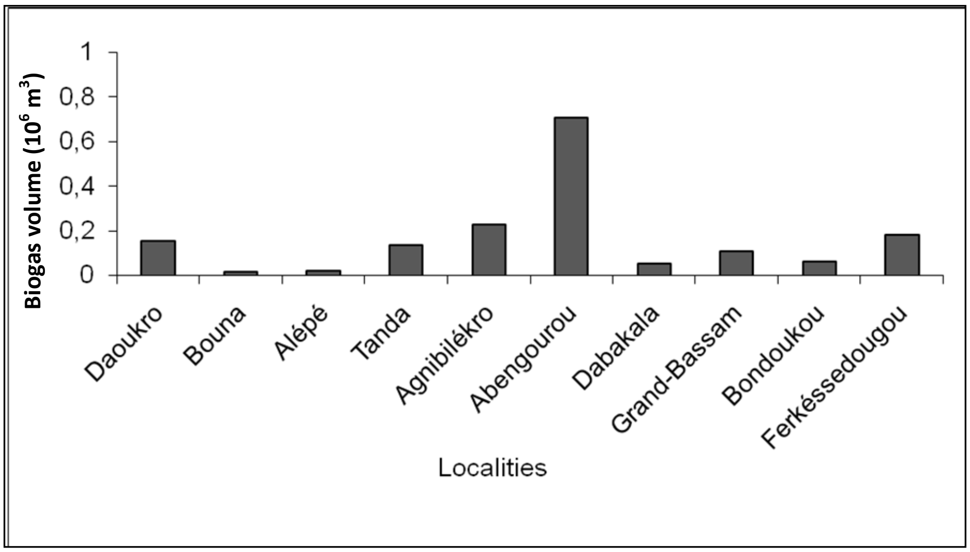

Figure 2: Annual biogas volume estimated from human excrement in the localities of Comoé river catchment.

Figure 3 shows the biogas volume of the animal manures. The total volume of biogas estimated from the animal manure was 110 x 10^6 m^3. Ferkessédougou and Bouna localities had the maximum volumes with respectively 47.6 x 10^6 and 29.9 x 10^6 m^3. Alépé (0.5 x 10^6 m^3), Agnibilikro (10^6 m^3) and Grand-Bassam (1.6 x 10^6 m^3) contained the lowest volumes of biogas estimated from the animal manure. The contribution of animal manure in biogas production varied from one area to another. But the proportion of biogas resulting from bovine dejections compared to volume estimated to the overall animal manure in the localities was very important at Ferkessédougou (86%), Bouna (83%), Dabakala (80%) and Daoukro (51%).Tanda, the contribution of caprine dejections (49%) was the most important in the biogas volume estimated in this locality. A similar result was obtained at Agnibilékro where the contribution of the bovine dejections into biogas volume was the most important (61%).-Bassam with 61%, the contribution of pig manure in the total biogas volume was the most important.

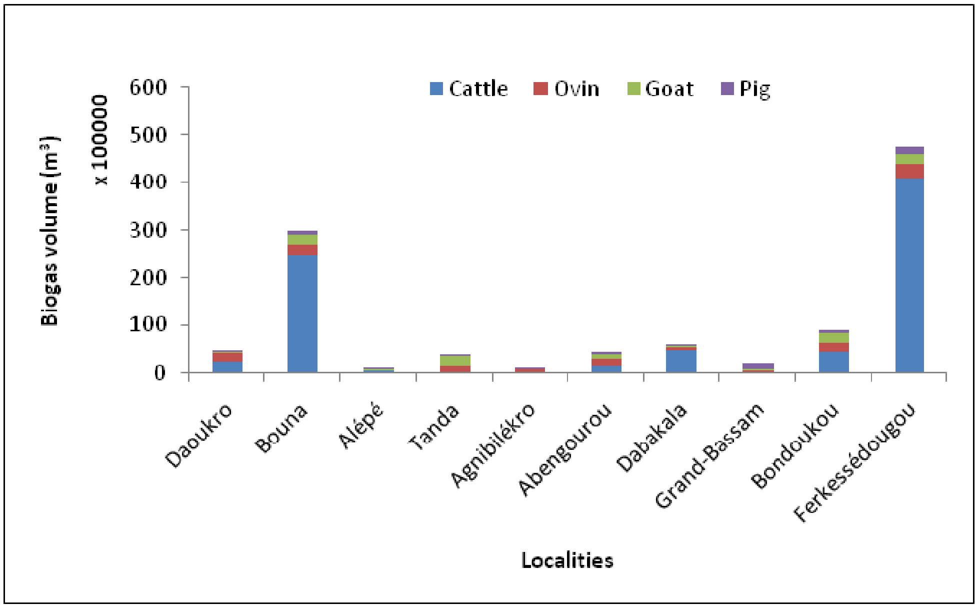

Figure 3: Annual biogas volume estimated from animal manures in the localities of the Comoé river catchment.

The biogas volumes obtained with the agricultural residues could be divided in two categories according to the type of speculation; residues of perennial and annual cultures. Figure 4 shows the biogas volume estimated from the residues of each type of perennial culture in the CRC. The biogas potential of the binomial coffee-cocoa culture residues dominated in five localities (Abengourou, Agnibilékro, Alépé, Tanda and Daoukro) over the ten. These volumes vary between 0.9 x 10^6 m^3 and 29.7 x 10^6 m^3 in these localities, of which 90 to 99% are due to the binomial coffee-cocoa wastes. Abengourou department with 29.7 x 10^6 m^3 contained the highest biogas volume resulting from the perennial cultures residues. The binomial coffee-cocoa cultures residues contributed about 99% of the aforesaid volume. At Grand-Bassam, the palm oil cultures residues contribute to more than 50% of the total biogas volume resulting from the perennial cultures residues. The lowest biogas volumes were obtained at Bondoukou and Ferkessédougou with respectively 0.08 x 10^6 m^3 and 0.002 x 10^6 m^3. Bouna and Dabakala localities do not contain perennial cultures.

Figure 5 shows the biogas volumes of annual cultures residues. The total biogas volume of these residues by locality is lower than 10 x 10^6 m^3, except in Bouna and Ferkessédougou. In these two latest localities, the total biogas volume of the annual cultures residues was important. However, Ferkessédougou (124.8 x 10^6 m^3) contained the highest total biogas volume. Conversely, Alépé locality (0.2 x 10^6 m^3) contained the lowest biogas volume. In general, there was a heavy contribution of corn culture waste (47 - 95%) in the total biogas volume per locality. The contribution of wastes was important by localities as follow: rice at Dabakala and Bondoukou, manioc at Agnibilékrou, and maize at Daoukro, Tanda, Abengourou, Grand-Bassam and Ferkessédougou. However, on the whole of the CRC, the residues of rice, cotton and maize cultures had the highest biogas volumes which were respectively 11.8 x10^6 m^3, 44.3x10^6 m^3 and 77.8 x10^6 m^3. The estimated biogas volumes of both of the agricultural organic residues (Figure 6) in localities of the North and Central (Bondoukou, Bouna, Dabakala, Ferkessédougou) were a heavy contribution of annual cultures residues (65 - 100%) than in southern of the basin (Alépé, Abengourou, Agnibilékro, Grand-Bassam, Tanda). In this latest area, the biogas volume resulting from the perennial cultures residues was the most important (55 - 96%) fraction in the total biogas volume. The locality of Ferkessédougou, with the strong contribution of annual cultures residues had the highest biogas volume of the CRC.

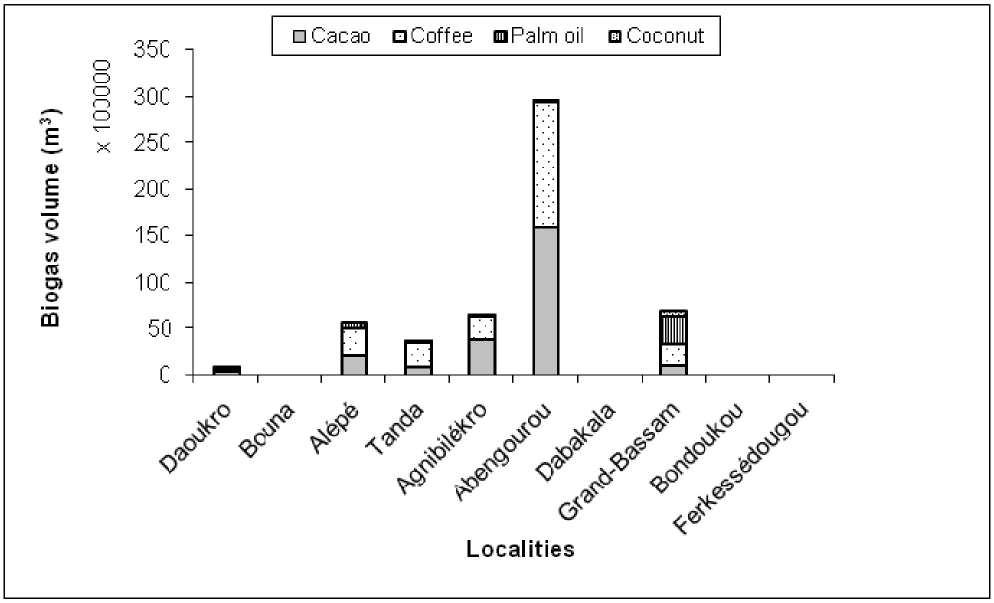

Figure 4: Annual biogas volume estimated from the perennial cultures residues in the localities of Comoé river catchment.

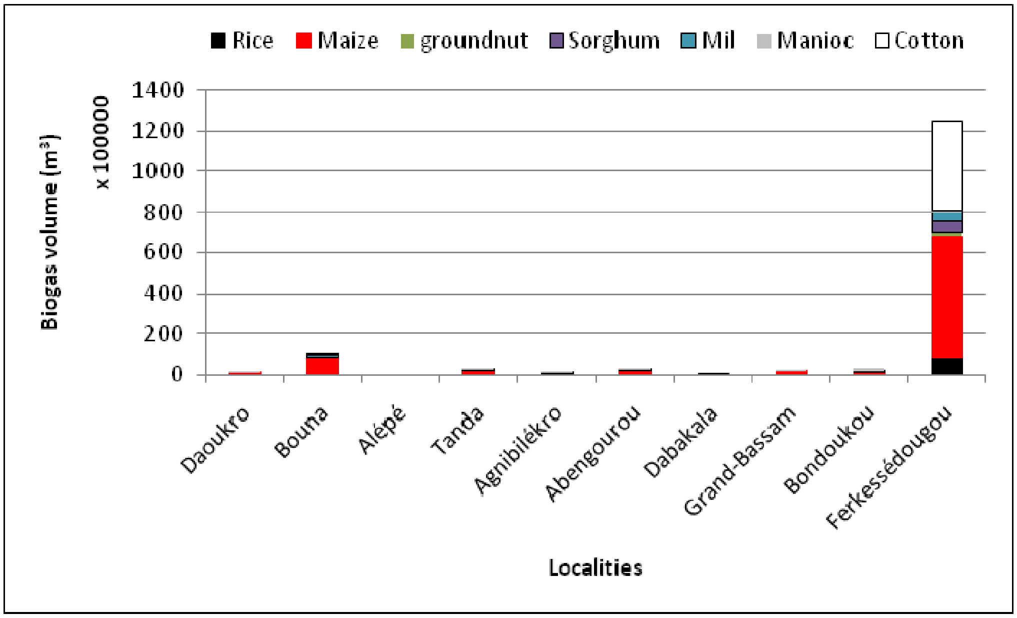

Figure 5: Annual biogas volume estimated from annual cultures residues in the localities of the Comoé river catchment.

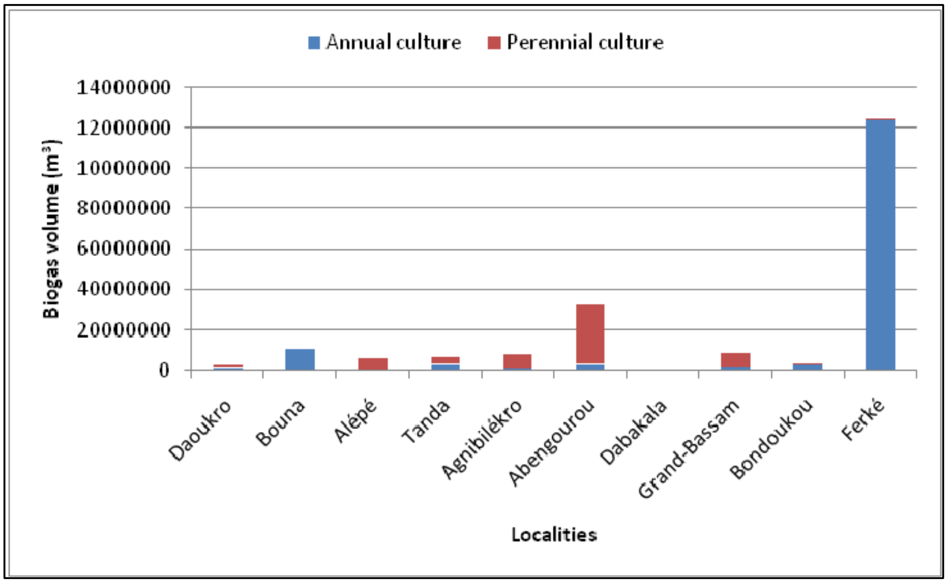

Figure 6: Annual biogas volume estimated from the agricultural residues in the Comoé river catchment.

Considering the whole organic residues biogas volume (Figure 7), one could note the notable influence of the biogas volume of agricultural residues on the total biogas volume within the localities, except in Bouna, Bondoukou, Dabakala and Daoukro localities.human excrement had account for a weak proportion in the total biogas volume within the localities. All things considered, Ferkessédougou department contained the highest biogas volume comparing to Daoukro, Dabakala and Alépé localities which had the lowest biogas volumes.

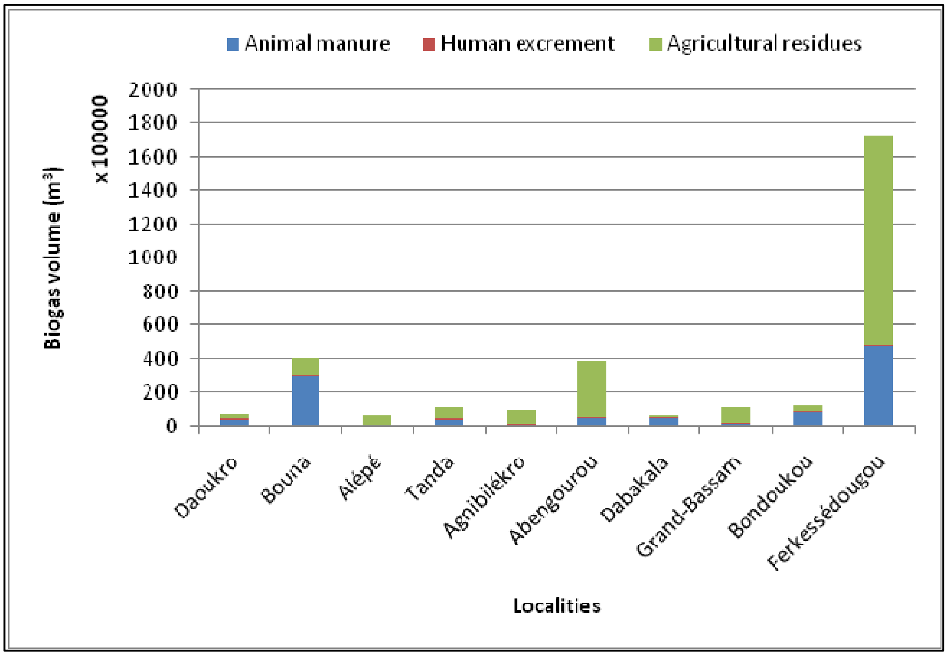

Figure 7: Annual total biogas volume estimated from agro-pastoral residues and human excrement in the localities of the Comoé river catchment.

The modes of utilisation of organic wastes in the CRC are presented in Table 3. Agricultural organic solids wastes are predominantly incinerated on the field, generating by this way gaseous pollutant in the atmosphere. Some portion agricultural residues are used to satisfy the domestic energy needs. Industrial valorisations of palm residues for vapour generation are done in the CRC. The stems of the food crops are generally composted on the field to improve soil organic quality. For both of the agricultural residues, any statistic exists on their utilisation. However, mass burning on the field and composting appeared to be the most significant practices. Human excrements are stored in septic tanks, latrines or disposed into the environment. The latest mode human excrements disposal can cause biological water pollution.

DISCUSSION

The biogas potential of human excrements of Abengourou is most important in the CRC. This result could be explained by elevated density of population in this locality. The settlement of the population in the aforementioned department is for coffee and cocoa cultures (Boutillier, 1971;Léonard & Vimard, 2005). Results have shown a high biogas volume from animal manure at Bouna and Ferkessédougou. This biogas volume in these departments was dominated by bovine dejections. Moreover the biogas volume estimated from bovine manure was about 41 x 10^6 m^3 at Ferkessédougou, corresponding to 86% of the total biogas volume of animal manures of this locality. These results could be explained by the fact that these localities established in the north of Côte d'Ivoire, are in an agro-ecological zone favourable to livestock in general and bovines in particular (FAO, 2003; Ndabalishye, 1995).

Concerning the annual cultures, the presence of corn scrap in all the localities is explained by the fact that the CRC offers pedo-climatic conditions favourable to its culture. For the biogas potential of perennial cultures residues, the volumes were dominated by the binomial coffee-cocoa wastes, except in Bondoukou and Grand-Bassam where the binomial coffee-palm waste dominated. The important contribution of the coffee and cocoa wastes into the biogas volumes could be explained by the intensive culture of these plants in the centre and the south of the basin, because of the favourable pedo-climatic conditions. These localities (Abengourou, Agnibilékro, Daoukro and Alépé) are considered as the old loop of the cocoa in Côte d’Ivoire. At Ferkessédougou coconut scrap were the only sources of perennial cultures residues that contribute to biogas volume. But at Bouna and Dabakala, there was any production of biogas from these cultures types residues. These results are explained by the fact Bouna and Dabakala are established in unfavourable areas for perennial plants cultures.The absence of manufacturing unit of biogas in the CRC, in spite of the availability of organic substrates in the aforementioned area could be explained by the absence of dissemination and vulgarisation policies of this technology in the rural areas as it is done in the Nepal, China and India (USAID, 2007).of biogas production at Korhogo, proposed a cost of 2 300 € per unit digester implementation. This cost is very an expensive for rural population in Côte d’Ivoire. One could take in account that plastic digesters were not considered in the aforesaid project. The disparity of organic substrates (livestock waste, agricultural and human excrement) in the CRC impacted the total biogas volume in the localities. This result could be explained by the unequally settlement of populations in the basin and the variability of agro-ecological zones. The variability of organic substrates for biogas production in the CRC governs the technological choices of biogas unit establishment.

Table 3: Agro-pastoral residues and human excrement valorization in the Comoé river catchment in Côte d’Ivoire.

Wastes typology			Waste utilization								
			Fodder	Burning on field	Combustion for energy	Confection of bed	Composting	Replanting	Dispose on farm	Construction	Biogas
Annual culture	Rice	Straw	*	*	*	*				*	
		Husk	*	*	*						
	Maize	Husk		*							
		cob		*	*						
		Stalk		*	*		*				
	Manioc	Stalk		*	*			*			
	Mil	Stalk		*	*		*				
Perennial culture	Cotton	Stalk		*	*		*				
	Coffee	Shell		*							
	Cocoa	Pod		*					*		
	Palm oil	Bunche		*					*		
		Coir		*	*						
		Shell		*	*						
Human excrement							*				
Animal manure				*	*						*

For example, the use of the human excrement for biogas production will require sensitizing populations on the use of this substrate because of the taboos and other paradigms (Duncker, Matsebe, & Moilwa, 2007). The exploitation of the aforesaid substrate in rural zone in addition to other organic substrates (animal manure and vegetable kitchen residues) could be performed in small biogas units to satisfy domestic energy needs. In the big localities like Abengourou, Agnibilékro and Ferkessédougou, the exploitation of human excrement for biogas production could be done only in centralized units towards which faecal sludge will be convoyed. The biogas potential from animal manures was unequally distributed in the CRC. Ferkessédougou and Bouna departments contained the highest biogas volumes. Semi-industrial, unit could be established in these localities to produce biogas from animal manures. However, the profitability of the process could be influenced by the manure transportation cost. In addition, the installation of small units of 6 m^3 on the livestock sites in the CRC would make it possible to solve at least partially, the requirements in energy of rural populations. This approach was applied successfully in Nepal, China and India (USAID, 2007). The results have also put in evidence that agricultural waste contained an important biogas volume. The valorisation of these wastes to biogas is a relatively complex technology which may require waste crushing before digestion. In addition, the acidification of the digesters makes difficult the utilisation of such substrates by non experimented persons. These substrates are not to be considered for domestic biogas production. However, they could be used for solid waste fermentation processes for biogas production in industrial level (Chanakya et al., 1999; Gunaseelan, 2004).

CONCLUSION

The biogas potential of agro-pastoral residues and human excrements in the Comoé river catchment area (CRC) has been investigated. The agricultural residues have the most important contribution in biogas total volume, in particular that of the binomial corn-rice cultures residues. Ferkessédougou, Bouna and Abengourou localities contained the highest biogas volumes. Decentralized units for biogas production from animal manures at Ferkessédougou, Bouna and Bondoukou seem to be the best option of production. However, for the exploitation of agricultural residues to produce biogas, manufacturing units could be established at Ferkesédougou and Abengourou where these wastes are abundantly produced. The production of biogas from agro-pastoral residues and the human excrement could permit the recovery of significant quantity of annual energy (1.2 GWh). The exploitation of this energy resource will contribute to the conservation of forest and reduce women occupation in searching for biomass energy. Finally, biogas production could generate financial resource and guarantee a better framework of life for women.

REFERENCES

Billaud, V. & Varagnat, F. (1983). Les dossiers du biogaz, Dossier A : La fermentation méthanique. Cellule *Biométhane du GERES*, Paris, 72p.

Boutillier, J. L. (1971). Croissance démographique et croissance économique en Côte d'Ivoire. *Cahier ORSTOM, Série des Sciences humaines*, volume VIII, 73-79.

Chanakya, H. N., Srikumar, K. G., Anand, V., Modak, J. & Jagadish, K. S. (1999). Fermentation properties of Agro-residues, leaf biomass and urban market garbage in a solid phase biogas fermented. *J. Biomass and Bioenergy* 16, 417-429.

Chanakya, H. N., Rajabapaiah, P. & Modak, J. M. (2004). Evolving biomass-based biogas plants: the ASTRA experience. *Current Science* 87, 917-925.

Cho, J. G., Park, S. C. & Chang, H. N. (1995). Biochemical methane potential and solid state anaerobic digestion of Korean food wastes. *Biores. Technol.* 22, 245-253.

Chynoweth, D. P., Owens, J. M. & Legrand, R. (2001). Renewable methane from anaerobic digestion of biomass. *Renewable energy* 22, 1-8.

Duncker, L. C., Matsebe, G. N. & Moilwa, N. (2007). The social/cultural acceptability of using human excreta (feces and urine) for food production in rural settlements in South Africa. Report to the Water Research Commission (WRC), TT 310/07.

FAO (1998). Proceedings of the Regional Expert Consultation on modern Application of Biomass Energy, FAO Regional Wood Energy Development programme in Asia, Report 36, Bangkok, 22p.

FAO (2003). Cattle and small ruminant production system in sub-Saharan Africa: a systematic review. Food and Agricultural Organization, Rome.

FAO (2005). Global livestock production and health atlas. Food and Agricultural Organisation, Rome (Accessed March, 2005).

Girard, G., Sircoulon, J. & Touchebeuf, P. (1971). Aperçu sur le régime hydrologique. In Avenard, J. M., Girard, M., Sircoulon, J., Touchebeuf, P., Guillaumet, J. L., Adjdnohoun, E. & Perraud, A. (Eds) Le milieu naturel de la Côte d'Ivoire. *Mémoire ORSTOM*, Paris 50 109-155.

Gowda, M. C., Raghavan, G. S. V., Ranganna, B. & Barrington S. (1995). Rural waste management in a south Indian village-A case study. *Biores. Technol*. 53, 147-164.

Gunaseelan, V. N. (2004). Biochemical methane potential of fruits and vegetable solid waste feedstocks. *Biomass and Bioenergy* 26, 389-399.

IEA (2000). World Energy Outlook, IEA, Paris, 2000.

IEA (2002). World Energy Outlook, IEA, Paris, 2002.

INS (2000). Statistique de la population de la Côte d'Ivoire, Abidjan, 2000.

Kivaisi, A. K. & Rubindamayugi, M .S. (1996). The potential of agro-industrial residues for production of biogas and electricity in Tanzania. *Wrec*, 917-921.

Kumar, A., Purohit, P., Rana, S. & Kandpal, T. C. (2002). An approach to the estimation of the value of agricultural residues used as biofuels. *Biomass Bioenergy* 22, 195-203.

Léonard, E. & Vimard, P. (2005). Crises et recompositions d'une agriculture pionnière en Côte d'Ivoire. Dynamiques démographiques et changements économiques dans le Bas-Sassandra (Côte d'Ivoire). *Collection Hommes et Sociétés*, Paris, IRD-Karthala, 368 p.

Mehretu, A. & Mutambira, C. (1992). Gender differences in time and energy costs of distance for regular domestic chores in rural Zimbabwe: a case study of the Chiduku Communal Area. *World Development* 20, 1675-1683.

Moller, H. B., Sommer, S. G. & Ahring, B. K. (2004). Methane productivity of manure, straw and solid fraction of manure. *Biomass Bioenergy* 26, 485-495.

Nabinta, R. T., Yahaya, M. K. & Olajide, B. R. (2007). Socio-economic implications of rural energy exploitation and utilization on sustainable development in Gombe State. *Nigeria J. Soc. Sci.* 15, 205-211.

Ndabalishye, I. (1995). Agriculture vivrière Ouest-Africaine à travers le cas de la Côte d'Ivoire. *Institut des savanes*, 383p.

Nelson, R. G., Walsh, M., Sheehan, J. J. & Graham, R. (2004). Methodology for estimating removable quantities of agricultural residues for bioenergy and bioproduct use. *Applied Biochemistry Biotechnology* 113, 13-26.
PNUD (2001). Biogas technology in agricultural regions, Tanzania. Project: Promotion of Low Cost Biogas Technology to Resource Poor Farmers in Tanzania, 3p.
PNUD (2003) Human Development, Report, New York, 15p.
USAID (2007) Biogas: Retrospect and prospect Georgia, rural energy program, 43p.
Wauthelet, M. (2001). La biométhanisation des déchets solides agricoles. Thèse de Doctorat, Université Catholique de Louvain, Belgique, 58p.
WHO (2000). Addressing the Links between Indoor Air Pollution, Household Energy and Human Health. Based on the WHO-USAID global consultation on the health impact of indoor air pollution and household energy in developing countries (Meeting report), Washington DC, 3-4 May.
Zhang, R. & Zhang, Z. (1999). Biogasification of rice straw with an anaerobic-phased digester system. *Bioresource technology* 68, 235-245.

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