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From Municipal Solid Waste to Energy: Possibilities in Abidjan (Côte d'Ivoire)

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ABSTRACT

The demand in electrical energy in Cote d'Ivoire is insufficient, the search of energy from alternatives sources is therefore necessary, through the diversification of energy sources and the gradual replacement of energy sources where it is necessary and possible. That is the moment where renewable energies could be involved, particularly biomass or bioenergy. Municipal solid wastes (food remains, papers, plastics, household refuse...) are suitable substrates for the production of energy.

The energy recovery of municipal solid waste in the city of Abidjan so far is not yet effective. The energy contribution of solid waste components such as, paper, plastic, food remains is still non-existent.

In this study, 3 scenarios of energy recovery of municipal solid waste for electricity generation are proposed. The first scenario uses the technique of "Landfill gas " (LFG), and the gas produced is converted into electricity. The second is the scenario of mass incineration (MI) where the waste are incinerated to produce electricity. Finally, the third scenario involves a combination of anaerobic digestion (AD) and refused fuel derived (RFD) to electricity production. The production of electricity from solid waste using these three different scenarios is compared. The scenario combining anaerobic digestion and refused fuel derived can generate the greatest amount of electricity compared to the other two scenarios. From this scenario, from 2015 to 2030 more15000 GWh of electricity could be generated in theme of estimation.

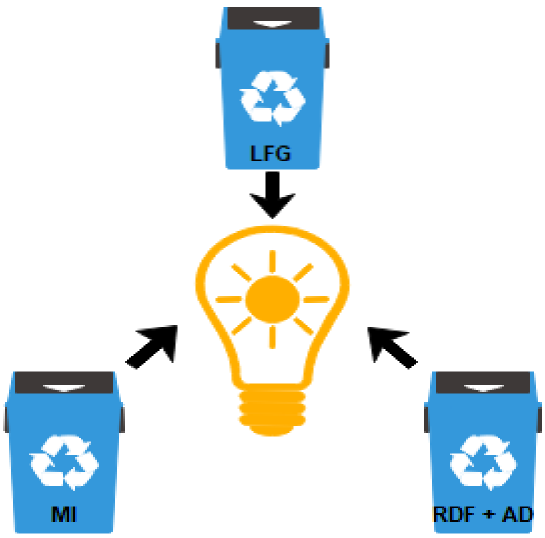

Figure 1: Abstract graph

KEYWORDS: *Municipal Solid Waste, scenario, Energy recovery, electricity production*

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I. INTRODUCTION:

Currently, rapid increase of the population and the growing number of industries are the major causes of the increasing production of municipal solid waste [1]. These untreated wastes can have harmful environmental effects, for example the emissions of greenhouse gases [2]. Municipal solid waste consists generally of remains of food, paper, plastics, glass and metals, and are abandoned in the environment in several ways, as in the dumps or landfills in Abidjan [3]. However, there are many methods of treatment of these waste, such as composting, incineration and anaerobic digestion, nevertheless, these techniques are still not effective in African countries [4]. Electricity can be generated by these different types of treatment, and it can be used to fill the deficit of electricity which suffer the majority of developing countries. In this sense, Municipal Solid Waste (MSW) management appears to be a promising and advantageous alternative in an environmental and economic context. Furthermore, good management of solid waste will lead to improved sanitation in urban areas and will reduce the greenhouse gas emissions [5]. In developed countries such as the United States and the Japan, municipal waste is already used to generate electricity for more than 20 years [2].

Abidjan, economic capital of Cote d'Ivoire, composed of 13 communes, currently has only a waste management limited, with no formal valuation. The informal channels of recovery are limited to a few initiatives or projects private limited or the activity of bargain hunters on the discharge. Indeed, the elimination of waste in that territory is being carried out through a simple deposit on a historical site operated for several decades, without appropriate planning [6].

The proposed valuation scenario is so respectful of the environment, combining goals of valuation wastes and minimization of the final waste management-related nuisances, and the reduction of emission of effluents. In this study, different scenarios of energy recovery for electricity production are compared.

II. METHODOLOGY

Description of study area – Abidjan

Abidjan is the economic capital of Côte d'Ivoire and represents 60% of the country's gross domestic product. It is the most populous city of the country with currently more than 4 000 000 inhabitants, more than 20% of the total population of the country and an area of 2 119 km^2[7]. The city of Abidjan is the most industrialized region of the national territory.

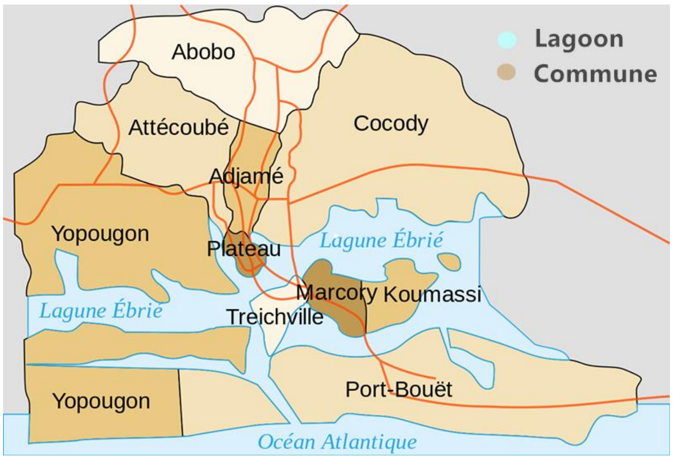

Figure 2: Map of Abidjan

Existing SWM (Solid Waste Management) Practice in Abidjan

The international Organization for the sustainable management and valorisation of waste and mineral raw materials "Gevalor" has carried out a study on solid waste management in the city of Abidjan. According to its report (Gevalor 2015), there is a considerable gap in the integrated management of household solid waste in the Abidjan district [8]. Nevertheless, since 2016, an integrated solid waste management agreement in the Abidjan district has been signed between the Ivorian state and American companies for operations including, inter alia, organic recovery (biofertilizers) and energy (biogas). But to date, no confirmation on the exact start date of these operations has been given.

Methods of Data collection

An exhaustive review of the literature provided the necessary data for this study, with Abidjan being chosen as the study area. Three scenarios were created to identify effective energy recovery options for the generation of electricity from waste in the city of Abidjan. Figure 3belowdescribes the methodological Framework.

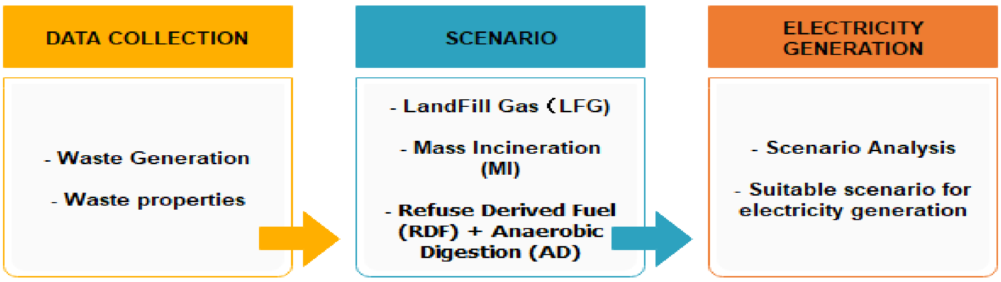

Figure 3: Methodological framework of this study

- Forecast of MSW Generation

The Forecast of MSW Generation in Abidjan is linked to the increase in population and economic development from 2015 to 2030.

-Scenario 1 – Energy from Landfill Gas Recovery LFG

In this scenario, it is considered that all waste is transported to the landfill excluding recyclable materials. It is assumed that all the waste transported to the landfill are subject to the recovery of LFG. This model of landfill gas is calculated according to the IPCC regulations [9]. The estimation of methane production is determined by equation (1).

$$Q_m = (M_T.P.MCF\ .DOC\ .\ DOCF\ .F\ .\ 16/12\text{-}R)\ .\ (1\text{-}OX).\ (1/D) \qquad (1)$$

Where: Q_m= Quantity of methane emission (m^3/yr);
M_T = Total MSW generated (Tonnes /yr).
P = Percentage of urban waste land filled;
In this paper, waste collected equals the quantity of urban waste sent to landfills, so P = 70%.
MCF = methane correction factor (fraction); with 0.6 as general default value
DOC = degradable organic carbon (fraction) (kg C/ kg SW) = Content of degradable organic carbon in the waste, recommended to be 15% by IPCC.
DOCF: fraction DOC dissimilated = Percentage of actually decomposed DOC in the waste (recommended to be 77% by IPCC)
F = fraction of CH4 in landfill gas (IPCC default is 0.5)
16/12 = conversion of C to CH4
R = recovered CH4 (Gg/yr) (R= 0)
OX = oxidation factor (fraction – IPCC default is 0)
D = Methane density $0.657.10^{-3}$ tons/m^3 (gas, 25 °C, 1 atm)

The method assumes that all the potential CH_4 emissions are released during the same year the waste is disposed of.

According to Bensmail et al. [10], the calorific value of the methane is close to 11 kWh/m^3. According to an EU report, the rate of conversion of the RDF from mixed waste is 23-50% [11]. Therefore, in this study, it is assumed that the gas is converted into electricity with an efficiency of 25%. From these power values, the electricity generated can be estimate throughout equation (2):

$$E_1 = Q_m.\ P.\ \eta_1 \qquad (2)$$

Where: E_1: Electricity generated (GWh/ yr)
Q_m: Quantity of methane emission (m^3/yr)
P: Calorific value of methane (GWh/m^3)
η_1(%): Yield factor of the motor/generator set

- Scenario 2 - Energy from Mass Incineration MI

In this scenario, it is assumed that all wastes excluding recyclable materials go to incineration. The collection rate determines the amount of waste. Mass incineration implies that unseparated waste is burned in a high temperature furnace in excess of oxygen. The Lower Heat Value (LHVar) represents the energy content of MSW in this study. LHVar of MSW in the city of Abidjan is 6.51 MJ/kg, which is shown in table 1. The efficiency of electricity production from incineration is 21% since the average efficiency rate is 15% to 27% [12].

Table 1: Waste fraction and assumed LHVar in Abidjan from Literature (Gevalor 2015)

Mass Basis Fraction	**% of Waste**	**LHV_{ar} (MJ/kg)**
Food and organic waste	45.3	1.91
Wood	12.4	9.31
Textiles	2.8	11.79
Paper & cardboard	6.3	6.44
Inert	1	-0.25
Fines	15.4	2.58
Plastics	16.7	20.14
Average	100	**6.51**

The electricity generated from incineration can be estimate throughout equation (3):

$$E_2 = M_T . LHV_{ar} . \eta_2 \quad (3)$$

Where: E_2: Electricity generated (GWh/ yr)
M_T: Total MSW generated (Tons /yr)
LHV_{ar}: Energy content of MSW (GWh/Tons)
η_2(%): Efficiency of electricity production from MI

-Scenario 3 – Energy from Refuse-Derived Fuel RDF + Anaerobic Digestion (AD)

This scenario is a combination of 2 scenarios, in which non-biowaste with a LHVar higher, such as paper, plastic, are taken as fuel derived from waste (RDF), which includes 25.8% of total MSW, and 57.7% of MSW that is the fraction of biowaste is sent to anaerobic digestion (AD). Glass, metal, inert, fines are not included in RDF. Calculated LHV_{ar} is 15.89 MJ/kg (Table 2). According to an EU report, the rate of conversion of RDF from mixed waste is 23-50% [13], so the value of 36.5% is retained in this study for calculation. RDF is supposed to be burned in a power plant to produce electricity. RDF power generation efficiency is supposed to be 25% (DEFRA 2014). According to a study (Motiva 2013) [14], the average biogas production from biowaste is 150-250 m3/ton with 65% of methane. 200 m3/ton (including about 60% methane is used to calculate the production of gas in this study. The lower calorific value of the methane is about 40 $MJ/m^3.N$ [15]. In this study, it is assumed that a spark ignition engine is used for the production of energy, and energy efficiency is 22-28% for biogas from waste [15]. Therefore, 25% is taken in this study for calculation.

Table 2: Waste fraction and assumed LHVar in Abidjan for RDF

Mass Basis Fraction RDF	% of Waste	LHV'ar (MJ/kg)
Textiles	2.8	11.79
Paper & cardboard	6.3	6.44
Plastics	16.7	20.14
Average	25.8	15.89

The electricity generated from the combination of RDF and AD can be estimate throughout equation (4):

$$E_4 = E_{RFD} + E_{AD} \quad (4)$$

With: $E_{RFD} = M_T . LHV'_{ar} . v . \eta_3$ Electricity produced from RFD
$E_{AD} = M_T . F . q . m . P . \eta_4$ Electricity produced from AD

Where: E_4: Electricity generated (GWh/ yr)
M_T: Total MSW generated (Tons/yr)
LHV'_{ar}: Energy content of MSW (GWh/Tons) for RFD
v : Percentage of waste taken as fuel derived from waste (RDF)
η_3 (%): Efficiency of electricity production from RDF
F (%): Fraction of biowaste in MSW
q: Average production of biogas from biowaste
m: Percentage of methane in biogas
P: Calorific value of methane (GWh/m^3)
η_4 (%): Efficiency of electricity production from AD

III. RESULTS AND DISCUSSION

- ***Forecast of MSW Generation***

In this study, the rate of waste production in Abidjan city was estimated from the study conducted by (Gevalor 2015) or 2015 was considered as a base year. This study reveals a forecast annual increase in per capita waste production of 7%/year between 2015 and 2020. Based on the waste production rate and population projection in this region, the forecast of MSW Generation between 2015 and 2030 can be seen in Figure 3. This figure 4 shows also that collected waste is 85% of total generated waste and the rest are recycled and illegally disposed.

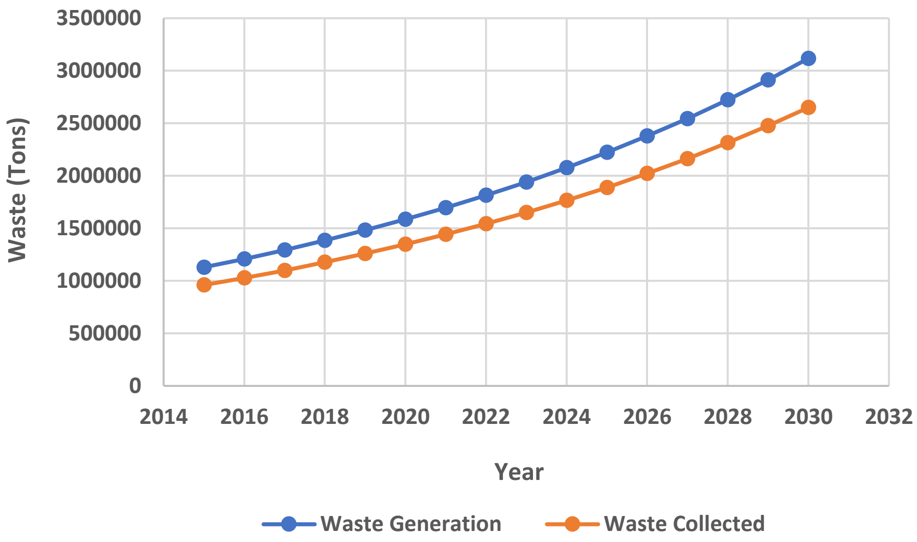

Figure 4: Forecast waste generation in Abidjan 2015 -2030 (tonnes per year)

By comparison, developed countries have a higher waste production per capita than developing countries [16]. Particularly, the average daily per capita production of waste in Côte d'Ivoire is between 0.2 kg/capita/day and 0.8 kg/capita/day [17]. The rational management of these wastes could have a positive impact on the whole chain of management of household solids through the production of energy that will benefit the region. According to Rojas, (2012) [18], the waste sector in Africa has a significant but insufficiently exploited social and economic potential.

- ***Scenario 1 – LFG Recovery***

Figure 5 shows the total production of methane gas for the period 2015-2030. It is assumed that the dump is opened in 2015 and closed 2030. Maximum gas production will be in 2030 with a value of 18, 076 m^3 per hour. As it is observed in figure 4, the recovered electricity from landfill gas continues to grow until 2030 with a value of 440 GWh.

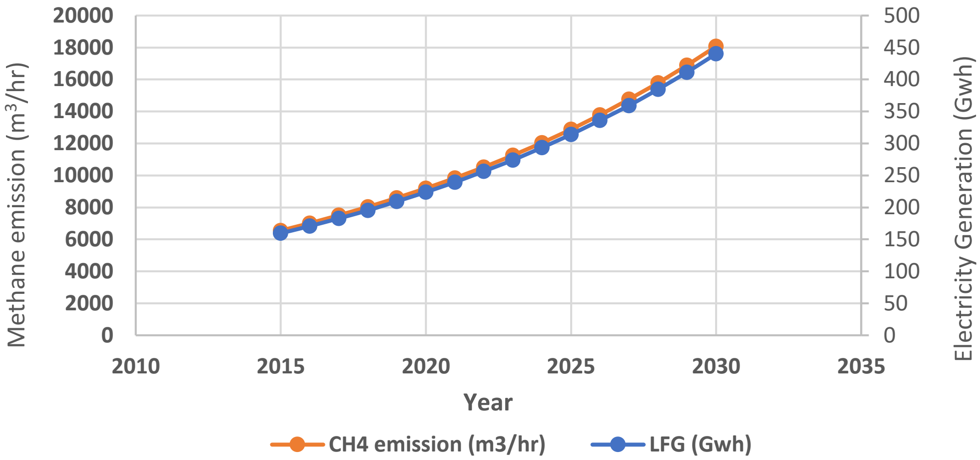

Figure 5: Electricity generation from Landfill Gas

- ***Scenario 2 - Mass Incineration MI***

As shown in Figure 6, the production of electricity from the incineration of mass is considerably higher than the production of electricity from landfill gas recovery. With the increasing amount of waste in the city of Abidjan, the energy from the incineration of mass increases by 403 GWh in 2015 to 1113 GWh in 2030. The total production of electricity generated from the incineration of mass between 2015 and 2030 is quite impressive, it is equal to 11247 GWh.

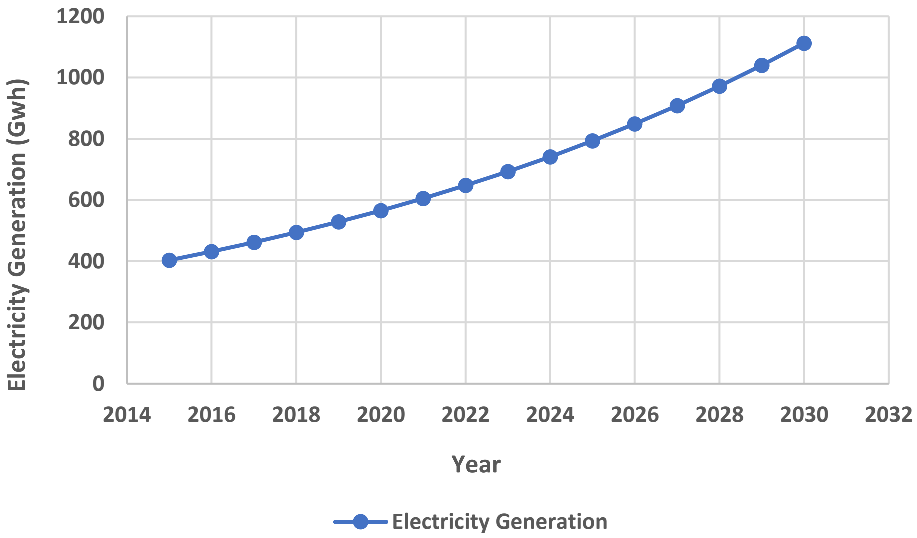

Figure6: Electricity generation from Mass Incineration

- ***Scenario 3 – Refuse Derived Fuel (RDF) + Anaerobic Digestion (AD)***

In this combined strategy, wastes are separated in RDF and biowaste. The energy generated from RDF and AD is calculated separately. The results in Figure 7 show that RDF power generation is high enough. From 2015 to 2030, the total amount of electricity production is about 14,000 GWh, meaning that RDF and AD generates approximately 9 000 GWh and 5,000 GWh of electricity, respectively.

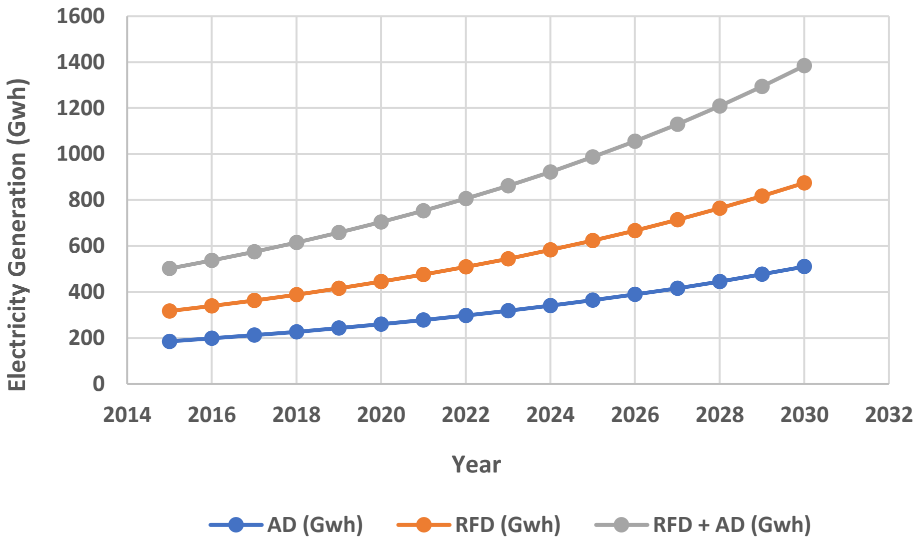

Figure 7: Electricity Generation from RDF + AD

Analysis – Summary

The total amount of electricity produced from 2015 to 2030 using three different scenarios is shown in figure 7. As it can be seen in figure 7, the amount of electricity produced from the combined strategy is superior to that of the other two scenarios. Although the quantity of gas from landfill in scenario 1 is not negligible, the production of electricity (4,449 GWh) is much lower compared to the other two scenarios. On the other hand, scenario 2 generates a quantity of electricity almost equal to 11,250 GWh. In summary, one can say that during the period 2015-2030, the quantity of electricity produced from scenario (RFD + AD) that is close to 14,000 GWh is the highest.

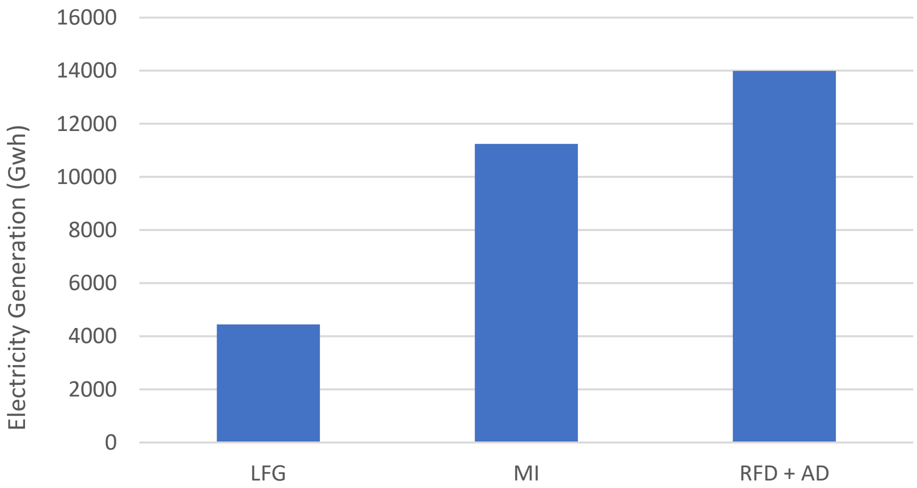

Figure 7: Total Electricity Generation from three scenarios from 2015 to 2030

The most important issue is that these technologies can be used to produce a considerable quantity of electricity but an integrated solid waste management system to achieve efficiency production is required. In developing countries, these scenarios are still non-existent. The collection, transportation and disposal of solid waste are the current challenges [19]. These scenarios in developing countries need to be implemented not only to protect the environment, but also to fill the energy deficit through the production of power from waste.

IV. CONCLUSION

The aim of this study was to identify an appropriate strategy for energy recover from solid waste in Abidjan city. In so doing, three scenarios of recovery of energy (electricity) are created and compared in terms of potential of electricity production. The results of this study show that scenario 3 has the highest potential of electricity generation. However, in order to implement this strategy combined, mechanical and biological treatment is necessary, and of course the construction of a plant of anaerobic digestion and combustion of RDF is also necessary. Côte d 'Ivoire government is seeking solution for energy recovery from these solids waste and this study is welcome to serve as direction. Of course, a comprehensive study should be conducted in this sense to better understand all the parameters related to this technology. Because Côte d'Ivoire is a developing country, the lack of capital can be a barrier to the application of such technologies for energy recovery. Nevertheless, the realization of such a project could fill a lot the lack of electricity which suffers small communities of the country. In the future, financing these technologies must be examined by considering the environmental healthy and the economic development of Côte d'Ivoire.

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