LIFE CYCLE ASSESSMENT (LCA) OF AGRICULTURAL RESIDUES (COCOA CORTEX, SUGARCANE BAGASSE AND OIL PALM FIBER) FOR POWER GENERATION IN BOILERS THROUGH FUEL COMBUSTION

Boni Yao Modeste [1,*], *Amal* Bouich [2], *Oyedele* Sampson Oladapo [1], *Noureddine* El Messaoudi [3,*], *Bernabé* Mari Soucase [2], *Aka* Boko [1]

[1]*Fundamental and applied physics laboratory of the basic and applied science training and research unit UFR SFA, Université Nangui Abrogoua (UNA) Abidjan, Cote d'Ivoire.*

[2]*Institute of Design for Automated Manufacturing and Production, Polytechnic University of Valencia, Spain.*

[3]*Laboratory of Applied Chemistry and Environment, Faculty of Sciences, Ibn Zohr University, Agadir 80000, Morocco*

Abstract Among the renewable energy resources available is biomass from agricultural waste. Herein, we propose 3 agricultural waste products (cocoa cortex, oil palm fiber and sugarcane bagasse. The environmental and energy performance of agricultural waste used as fuel to produce 1 kWh of electricity each in Ivory Coast was studied using the Life Cycle Assessment method. LAM is a method of environmental evaluation. It evaluates the environmental impact of a product over its entire life cycle. the life cycle of each of these 3 agricultural wastes is made up of collection, transport to the electricity production site and combustion of these biomasses in the boilers of the cogeneration units. The results are as follows: In terms of global warming impacts, for these 3 waste products (cocoa cortex, oil palm fiber and sugarcane bagasse) respectively (0.12; 0.16 and 0.19) kg CO2 eq. / kWh. In terms of impacts on the depletion of non-renewable resources for these 3 wastes (cocoa cortex, oil palm fiber and sugarcane bagasse) respectively (0.007; 0.010 and 0.012) MJ / kWh. In terms of eutrophication-related impacts on global warming for these 3 wastes (cocoa cortex, oil palm fiber and sugarcane bagasse) respectively (0.38; 0.4 and 0.91) g PO43-/ kWh. According to the results of the 3 impacts taken into account in this LCA study, it is desirable to use these 3 agricultural wastes to produce electricity with very good energy and environmental performance, instead of fossil fuels (diesel, oil and coal). Finally, the objective of this research will be to provide credible information to decision-makers (governments, private and public companies, national and international organizations and the general public) in order to promote the installation of energy production units (heat and/or electricity) based on the combustion of these 3 agricultural residues in rural and industrial areas.

Keywords

Agricultural waste ; boilers ; cogeneration units ; depletion of non-renewable resources ; eutrophication and environmental and energy performance ; impacts on global warming and life cycle assessment (LCA).

1. Introduction

To satisfy the world's growing need for energy (heat or electricity), the combustion of agricultural residues appears to be one of the best solutions for producing large quantities of energy. However, the lack of data on the environmental impact of burning certain types of agricultural waste to produce energy means that cogeneration units using biomass as fuel are not being set up in certain regions of the world. Among the range of methods used to measure a product's environmental performance, Life Cycle Assessment (LCA) appears to be the most suitable for carrying out this study. LCA is a method of assessing environmental impacts and therefore quantifying a product's performance throughout its life. The life cycle begins with the production stage of the raw materials used to manufacture the product and ends at the end of the product's life, passing through the production and use stages. This is known as "cradle-to-grave" assessment **[1].**

The first known Life Cycle Assessment study was carried out by Coca-Cola in 1969 to determine whether or not it was beneficial to manufacture metal cans from an environmental point of view **[2,3]**. The beginning of LCA studies therefore dates from the end of the 1960s and the beginning of the 1970s when the concerns were related to the consumption of energy and raw materials, as well as the treatment of waste. The first LCA studies were therefore related to these themes **[2, 4].** During the 1970s and 1980s, the use of Life Cycle Assessment remained limited due to a lack of knowledge of the method. Its use has remained confined to producers of packaging as well as politicians responsible for waste management. Because of the energy crisis of 1973, energy was the main focus of these studies **[2, 4].** The environment and the consequences of human actions on it will experience growing interest in the 1980s, following chemical disasters such as the Bhopal accident in 1984 or the nuclear explosion at Chernobyl in 1986. then, the LCA method remained relatively in the shadows until then will arouse renewed interest, especially in the field of packaging **[2]**. However, LCA leading to different results for the same products is controversial and leads to much debate **[2, 4].** In the 1990s, the Life Cycle Assessment method experienced a period of harmonization where the different experiences and achievements obtained during the last two decades were pooled. The Society of Toxicology and Environmental Chemistry in Europe (SETAC) takes charge of the organization of conferences and working groups for the improvement of the method. A society was also created in 1992 (SPOLD: Society for the Promotion of Life Cycle Development) for the development of public and accessible databases. A code of conduct was published in 1993 **[5]** in order to obtain harmonization in the steps necessary for such a study. ISO standards are then developed to show the way to carrying out an LCA (Baumann and Tillman, 2004a). Far from solving all the problems, but giving avenues for improvement, the European standards were created in 1998 and updated in 2006. The ISO 14040 standard (International Standardization Organization, 2006a) defines the principles and framework of the Life Cycle Assessment, while the ISO 14044 standard (International Standardization Organization, 2006b) **[6]** brings together the technical content necessary for the proper conduct of an LCA. However, these standards remain imprecise on how an LCA should take place.

Through the life cycle analysis (LCA) method, this research will study the environmental and energy performance of these 3 ((cocoa cortex, oil palm fibers and sugar cane bagasse) agricultural residues used as a source of energy to produce electricity.From their combustion in boilers where the heat obtained at the exit will make it possible to turn a turbine which by electromagnetic phenomena will then produce electricity.This LCA study will use the conventional LCA method CML 2001 (Center of Environmental Science of Leiden University (Netherlands) widely used which has impact characterization data on approximately 1000 substances **[7]**. Then compare the environmental impacts of each waste with each other and then with those of diesel.

2. Materials, techniques and methods used

2.1 The waste investigated

The waste studied are cocoa cortex, oil palm fibers and sugar cane bagasse. These agricultural residues will be dried and then crushed before the char physical and chemical properties **[11],** figure **1** below:

Fresh Cocoa Cortex

Fresh sugar cane bagasse

Fresh Oil Palm Fibers

Figure 1: waste used

2.2 Characterization of waste physical and chemical properties

2.2.1 Immediate analysis of agricultural waste

According to previous studies, the results obtained are shown in the following **table (1)** :

Table 1: immediate analysis

Samples	**Moisture content**	**Ash content (%Ash)**	**Organic matter content**	**(Organic carbon content (%CF)**

	(%HU)		**(%MO)**	
Oil palm fibers	3.60	18.80	81.20	47.07
Sugar cane bagasse	24.78	9.69	90.31	52.35
Cocoa Cortex	43.12	23.88	76.12	44.12

These results will be important for the study of the LCA of this waste

2.2.2 Chemical analysis of agricultural waste ash

The combustion of 0.5 g of each agricultural residue was carried out in the electric boiler adapted to the laboratory, then the ashes were collected. The chemical analysis of the ash of each agricultural waste was then carried out by SEM (Scanning electronic miscroscope) and the results are presented in the following **table (2):**

Table (2): chemical analysis of the ash of each agricultural waste used

chemical elements % content	Oil palm fibers	Sugar cane bagasse	Cocoa Cortex
C	0,69	1,11	1,43
O	0,52	0,99	0,83
Na	0,05	0	0,1
Mg	0,08	0,15	0,08
Al	0,06	0	0
Si	0,12	0,11	0,48
P	0,08	0,15	0,1
S	0,04	0,13	0,06
K	0,1	1,04	0,25
Ca	0,07	0,48	0,13
Fe	0,09	0	0,11
Cl	0	0	0,08

2.3 Determination of the higher Calorific Values PCS of the agricultural waste studied

The calorific values (PCS) of the waste were obtained through our previous studies and their lower calorific values (NCV) were deduced through the following equation (**1**)**:**

$$PCI = PCS - 0.225 \times H \qquad (\mathbf{1})$$

With, H which is the mass percentage of hydrogen (H = % H) contained in the waste sample. And determine by calculating H = (%Hu) / 9, where % Hu is the rate humidity of the waste.

Then the quantities of heat deduced in previous works by equation (2) below:

$$Q = m_{comb} \times PCS = \left(m_{ini} - m_{final}\right) \times PCS \qquad (\mathbf{2})$$

The results are presented in the **table (3)** according to previous work**:**

Table (3): Higher Calorific Value and Lower Calorific Value and Heat Released

Samples	**Oil palm fibers**	**Sugar cane**	**Cocoa Cortex**

		bagasse	
PCS (MJ/kg)	28.46	23.69	37.66
PCS (kWh/kg)	7.906	6.581	10.461
PCI (MJ/kg)	28.459	23.684	37.649
PCI (kWh/kg)	7.905	6.579	10.458
Amount of heat released Q (kJ)	14.23	11.845	18.83
Amount of heat Released Q (Wh)	3.953	3.292	5.231

2.4 LCA life cycle analysis methodology

Life cycle analysis (LCA) is a standardized assessment method (ISO 14040 and 14044) for carrying out a multi-criteria and multi-stage environmental assessment of a system (product, service, company or process) on its entire life cycle. Its purpose is to know and be able to compare the environmental impacts of a system throughout its life cycle, from the extraction of the raw materials necessary for its manufacture to its end-of-life treatment (disposal of waste, recycling, etc.) , through its phases of use, maintenance and transport (from the cradle to the grave) figure **(2)** below :

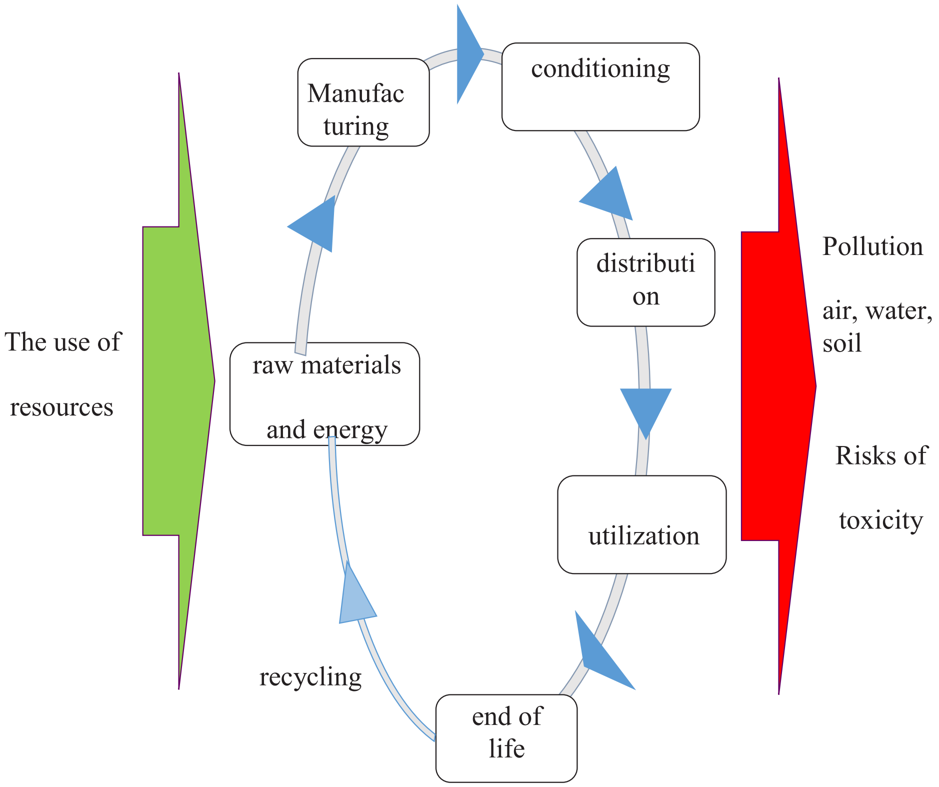

Figure (2): the life cycle of a product

Since 1972, technological progress and advances in environmental science have led to the revision of some of the assumptions of the Meadows report **[8].** But the existence of natural limits to growth has been confirmed by the climate change risk assessment. The term "sustainable development" was proposed in 1980 in the World Conservation Strategy published by the International Union for Conservation of Nature (IUCN, created in 1948), the World Wildlife Fund (WWF, established in 1961) and the United Nations Environment Program (UNEP, established in 1972) **[9].** This new term seeks to translate the objective of reconciling the development of human societies and the conservation of nature. Sustainable development achieved international recognition with the creation in 1983 of the UN World Commission on Environment and Development (Brundtland Commission). Sustainable development is defined as having to “meet the needs of the present without compromising the ability of future generations to meet theirs” **[10].** The Life Cycle Analysis, or LCA, comes from this requirement of sustainable development. It provides a method for quantifying the potential environmental impacts of a product, service or process. The first normative tools framing impact studies appeared in 1997 with the ISO 14040 standard, revised in 2006. LCA is now commonly used to compare the environmental impacts of different technological solutions or scenarios for the production of a good or service. It is governed by the ISO 14040 (Environmental management - Life cycle analysis - Principles and framework) and ISO 14044 (Environmental management - Life cycle analysis - Requirements and guidelines) standards [ISO, 2006a, 2006b]. ISO 14044 replaces and supersedes three other now obsolete standards: ISO 14041 40 (Definition of purpose and scope and analysis), ISO 14042 (Life cycle impact assessment) and ISO 14043 (Interpretation of the life cycle). The Life Cycle Assessment comprises several stages, presented in Figure 11 **[11].** 1) Definition of the limits of the system and of the functional unit 2) Life Cycle Inventory (LCI): this involves make the material and energy balance of the system in order to list all the incoming and outgoing flows, reported to the functional unit. 3) Impact assessment: the results of the LCI are transformed into potential impacts by applying impact characterization factors. Each element of the inventory and each impact corresponds to a characterization factor. These factors can have significant uncertainty **[12].**

2.5 Life cycle analysis of the agricultural residues studied

Our life cycle assessment (LCA) study of the biomass from our agricultural residues will enable us to assess 3 environmental impacts, namely :

- the impact on global warming ;
- the impact on the depletion of non-renewable energy resources (fossil fuels); and
- eutrophication.

According to the ISO 14040 standard (International Standardization Organization 2006a), we are going to carry out the LCA of our biomasses through the application of 4 fundamental stages: the phase of defining the objectives and scope of the study, the impact inventory phase, the impact assessment phase and the results interpretation phase.

2.4.1 The phase of defining the objectives and scope of the study

2.4.1.1 LCA objective

The aim of our LCA study is to assess the environmental impacts associated with both the production and combustion of each of the agricultural residues studied in small cogeneration units in order to obtain electricity. The environmental performance of the various biomasses studied will then be compared with each other and with that of diesel fuel.

2.4.1.2 The functional unit (U F)

The functional unit U F is the production of one tonne (1t) of agricultural residues "from the fields to the boiler furnace" and its combustion to produce electricity "from the boiler furnace to the alternator of the cogeneration unit". And our results will be reduced to the production of 1 kWh of electricity from the biomass studied to allow comparison with diesel.

2.4.1.3 System boundaries

In our LCA study, we consider all the relevant stages in the life cycle of our agricultural residues that are likely to contribute to the consumption of resources and the emission of pollutants into the environment. We therefore consider the following stages:

Production of agricultural waste: agricultural waste is collected from the fields and transported by lorry over short distances (50 km) from the fields to the cogeneration unit in the same area. The agricultural waste is then crushed using the cogeneration unit's mechanical crusher.

Combustion of the shredded agricultural residues: initially to produce heat which will then be converted into electricity using the alternator of our cogeneration unit **[1].**

2.4.1.4 The target audience

This study will enable us to provide more information and arguments to decision-makers in international organisations, private or public companies and the governments of the various countries. In order to promote the installation of small cogeneration units to produce electricity in rural areas from the combustion of agricultural residues.

2.4.2 Inventory analysis

This inventory analysis will consist of quantifying the resources consumed and identifying the pollutant emissions into the environmental atmosphere. To do this, it will be important to quantify, for each stage identified when the system boundaries were drawn up, the flows of incoming and outgoing products, which will then make it possible to assess the resources consumed and identify the discharges into the environment.

2.4.2.1 Production of agricultural residues (from the fields to the boiler hearth)

One (1 t) tonne of agricultural waste is collected in the fields and then transported 50 km to the boiler hearth by a lorry, which will consume 39.5 MJ of diesel. According to the Gabi LCA software, which shows that transporting 1 tonne of product over a distance of 100 km by lorry consumes 79 MJ of diesel **[13].**

2.4.2.2 Combustion of crushed agricultural residues (from the boiler furnace to the alternator of the cogeneration unit)

The combustion of 1 tonne of each crushed agricultural residue in the furnace of our cogeneration unit will produce a certain amount of heat which will then be converted into electricity by turbines through electromagnetic induction phenomena. A number of gases and pollutants will then be released, including CO_2, CH_4, N_2O, CO, COnV, SO_2, PM_{10} and $PM_{2.5}$.

a. Quantity of energy produced

According to equation **(3)**

$$Q = m_{comb} \times PCS = (m_{ini} - m_{final}) \times PCS \qquad (\mathbf{3})$$

And considering the results obtained in the table ( ) below during experimental work carried out on the combustion of 0.5 g of each agricultural waste studied. The quantities of energy produced are shown in the **table (4)** :

Table (4) : amount of heat released

Samples	**Oil palm fibers**	**Sugar cane bagasse**	**Cocoa Cortex**
PCS (MJ/kg)	28.46	23.69	37.66
Amount of heat released Q (kJ)	14.23	11.845	18.83
Amount of heat Released Q (Wh)	3.953	3.292	5.231

The quantities of heat resulting from the combustion of 1 tonne of each crushed agricultural residue were deduced. Then, with an efficiency of 50%, the cogeneration unit produces electricity **[14]** and the results obtained are presented in the table **(5)** below.

Table (5) : Energy released

Samples	**Oil palm fibers**	**Sugar cane bagasse**	**Cocoa Cortex**
Amount of heat released Q (MJ)	28460	23690	37660
Amount of heat Released (kWh)	7906	6581	10461
Electricity (MJ)	14230	11845	18830
Electricity (kWh)	3953	3292	5231

b. Quantity of pollutant emissions into the atmosphere

The quantities (in ppm and ppb) of certain gases (CO_2, CH_4, N_2O, CO) released into the atmosphere were obtained using MQ sensors connected to Arduino boards via a computer to detect, quantify and record these gases at regular intervals of 1 min, during the combustion of 0.5 g of each of the agricultural wastes studied in the adapted electric boiler. The results obtained represent the average of the various readings recorded for each gas released over a 2-minute period table **(6)** below.

Table (6) : quantities of gases CO_2 (ppm) and CH_4 (ppb)

Samples	**Oil palm fibers**	**Sugar cane bagasse**	**Cocoa Cortex**
CO_2 (ppm)	442	441	444
CH_4 (ppb)	268	262	251

With, ppm (parts per million) and ppb (parts per billion) according to current environmental standards **[15]**
The table **(6)** above can be used to deduce the quantities of these atmospheric pollutants relative to the combustion of 1 tonne of each of the agricultural residues. And according to the balance equation for the complete combustion of methane, the results obtained are presented in the following table (**7**).

Table (**7**) : quantities of gases released for the combustion of 1 tonne of each waste

Samples	**Oil palm fibers**	**Sugar cane bagasse**	**Cocoa Cortex**
CO_2 (t CO2 éq./ t biomasse)	0,894	0,882	0,888
CH_4 (kg CO2 éq./ t biomasse)	1,474	1,441	1,3805

c. The environmental impact of pollutant discharges

The 3 environmental impacts taken into account in our LCA study are modelled using the CML 2001 method (Center of Environmental Science of Leiden University) developed by the Institute of Environmental Sciences at Leiden University in the Netherlands in 2001. This is a more widely used methodology and is often considered to be more comprehensive.

- Impacts on global warming I_{RC}

The characterisation factor used to translate and express the various impacts on global warming of the substances used in this LCA study is the Global Warming Potential (GWP) over 100 years. Generally speaking, the Global Warming Potential (GWP) is defined by the integration, over a given period of time, of the radiative forcing (increase or decrease in the exchange of energy by radiation) generated by 1 kg of this gas, injected instantaneously into the atmosphere. The GWPi of a gas i is reduced to that of CO_2 and is calculated using the following equation:

$$GWPi = \frac{\int_0^{TH} a(i).C(i)dt}{\int_0^{TH} a(CO2).C(CO2)dt}$$

With:

GWPi: Global Warming Potential of gas i expressed in (kg CO2 equivalent / kg of gas) or (kg CO_2 eq / kg of gas i).
TH: Time Horizon (TH = 20, 100, 500 years) during which the calculation is considered;
a(i): absorption of thermal radiation following an increase in the concentration of gas i (in $W.m^{-2}.K^{-1}$);
C(i): concentration of gas i remaining at time t, $C(i) = e^{-\frac{t}{\tau i}}$ where, τi: adjusted life time for gas i ;
$C(CO2) = a0 + \sum_{P=1}^{3} ap.e^{-\frac{t}{\tau p}}$ (most recent model of the carbon cycle from Bern using a background concentration of 378 ppm [1]),
With: $a_0 = 0.217$; $a_1 = 0.259$; $a_2 = 0.338$; $a_3 = 0.186$;
and τ_1 =172.9 years ; τ_2 =18.51 years ; τ_3 =1.186 years.
Thus the general representation table according to **[16]** life time and greenhouse gas GWP is in the table **(8)** below :

Table (8) : life time and greenhouse gas and PRG en (kg éq CO_2 / kg de gaz)

Gaz	Durée de vie (an)	PRG en (kg éq CO_2 / kg de gaz)		
		20 ans	100 ans	500 ans
Dioxyde de carbone (CO_2)	100	1	1	1
Méthane (CH_4)	12	72	28	7,6
Oxyde nitreux (N_2O)	114	298	298	153
Tétra fluorure de Carbone (PFC-14)	50 000	5 210	7 390	11 200
Trifluorométhane (HFC-23)	260	9 400	12 000	10 000
Hexafluorure de soufre (SF6)	3 200	15 100	22 200	32 400

-Impacts on the depletion of non-renewable energy resources I_{ER}
The impacts on the depletion of non-renewable energy resources used in this LCA study are represented by the Lower Calorific Value (LCV) expressed in (MJ/kg) of the non-renewable resource i consumed during the various stages of the LCA. The main indicator considered for IER will therefore be expressed in MJ.

-Eutrophication I_E
This environmental impact is due to the significant presence of N and P type nutrients in the aquatic environment, which results in the development of algae to the detriment of certain less resistant biomass varieties. The CML 2001 method uses eutrophic power (EP) as a characterisation factor, measured with the indicator in PO_4^{3-} equivalent units. This involves converting the N and P atoms contained in the (algal) biomass into equivalents. This impact will be calculated in our LCA study on the basis of the quantities of N and P atoms present in the SEM chemical analysis of the ash from our agricultural waste.

2.4.3 Impact assessment or calculation

To assess the environmental impacts of our LCA study of agricultural residues, we have chosen the OpenLCA LCA software, which is freely available and allows us to integrate the chosen method. We will be using the CML 2001 methodology to model the impacts of interest to us. All its scientific foundations are accessible and transparent **[17]**. Our OpenLCA LCA software, which incorporates the CML 2001 method, will enable us to identify and classify the resources and then the pollutant discharges identified during the analysis of the inventory into the environmental impacts to which they are linked. The software will then translate these resources and discharges into environmental impacts by multiplying their quantities by the characterisation factors included in the CML methodology, which relate to 3 environmental impacts (impact on global warming, impact on the depletion of non-renewable energy resources and eutrophication).The two pollutant gases used in this LCA study to calculate the impacts on global warming are carbon dioxide (CO_2) and methane (CH_4).The Table **(9)** below for the method used to calculate the impact.

Table (9) : impact calculation method

Classification		Traduction en impacts environnementaux	
Analyse de l'inventaire	Impacts environnementaux	Facteurs de caractérisation	Calcul de l'impact (Indicateur)
CO_2	Impact sur le réchauffement climatique	Pouvoir de Réchauffement Global	CO_2 équivalent
CH_4			
N_2O			
Gaz naturel	impact sur l'épuisement des ressources énergétiques non renouvelables	Pouvoir Calorifique Inférieur PCI	MJ
Pétrole (gazole)			
Charbon			
NO_3	Eutrophisation	Pouvoir eutrophisant	PO_4^{3-} equivalent
N			
P			

2.4.3.1 Calculating the global warming impact I_{RC}

The global warming impact I_{RC} is calculated using the following formula:

$$I_{RC} = \sum_i mi \times GWPi$$

With,

I_{RC}: is the impact on global warming (measured in CO_2 equivalent) ;

mi: is the quantity of substance "i" with a global warming impact (greenhouse gas) identified during the inventory analysis;

$PRGi$: is the global warming potential of substance "i", identified during the inventory analysis and having an impact on global warming (measured in CO_2 equivalent).

The table ( ) above shows the main substances contributing to global warming and their GWP over 100 years.

2.4.3.2 Calculation of the impact on the depletion of non-renewable energy resources I_{ER}

The assessment of the impact on the depletion of non-renewable energy resources I_{ER} is obtained by multiplying the quantities of non-renewable energy consumed by their energy content (PCI) according to the following formula:

$$I_{ER} = \sum_i mi \times PCIi$$

With,

I_{ER}: is the impact on the depletion of non-renewable resources (measured in MJ) ;

m_i: is the quantity of non-renewable resource (fossil fuels) "i" consumed and identified during the inventory analysis (measured in kg) ;

PCI_i : the Lower Calorific Value of the non-renewable resource i consumed and identified during the inventory analysis (measured in MJ/kg).

The table ( ) below shows the main non-renewable energy resources with their Lower Calorific Values (LCV) :

Table (10) : Lower calorific value of some non-renewable energy sources **[18]**

Energie non renouvelable, fossile	PCI (MJ/kg)
Charbon	26,7

Gaz naturel	38,4
Pétrole brut	38,4
Gazole	45

2.4.3.3 Calculation of the impact on Eutrophication I_E

The impact on Eutrophication I_E is calculated using the following formula:

$$I_E = \sum_i mi \times PEi$$

With,

I_E : is the "Eutrophication" impact (measured in PO_4^{3-} equivalent) ;

mi: is the quantity of substance "i" released into the environment and contributing to eutrophication

PEi : is the eutrophying power of substance "i" contributing to the eutrophication impact (measured in PO_4^{3-} equivalent).

Thus table ( ) summarises the eutrophying powers of substances likely to produce N and P atoms that make up algal biomass.

Table (11): Eutrophication potential of a number of substances (Life cycle assessment applied to first-generation biofuels in France**, [19].**

Substances contributrices à l'eutrophisation	Milieu d'émission	PE (PO_4^{3-}équivalent)
Phosphore	Air, sol, eau	3,06
Phosphate	Eau	1
Acide phosphorique	Air	0,97
Azote	Sol, eau	0,42
Ammoniaque	Air	0,35
Ion Ammoniaque	Eau	0,33
Oxydes d'azote	Air, eau	0,13
Nitrate	Air, eau	0,1
Nitrite	Eau	0,1

2.4.4 Interpretation of the results

The phase of interpreting the results of the LCA study of our biomasses will enable us to draw conclusions from our study while proposing improvements and prospects for the continuation of our research. This part will be detailed in parts 3-results and discussion, then 4-conclusion and outlook.

3 Results and discussions

3.1 Results and discussions about the chemical analysis of the ashes

Despite the low content of mineral matter and alkali or alkaline earth metals, the waste must be dried thoroughly before combustion in the boilers. And clean the hearths of the boilers after several combustions because these inorganic materials and alkali metals contained in the ashes can create problems of corrosion and agglomeration at a certain combustion temperature **[20].**

3.2 The results of the calculations of the environmental impacts during the production of energy from waste

30% of total CO_2 emissions are used by plants for growth **[21].** And the quantity of eutrophication generated by each agricultural waste is deduced by the phosphorus P content of their ash obtained through chemical analysis of the ash with the SEM.

Table (12): For cocoa cortex

Etapes de l'analyse du cycle de vie	Impact sur le réchauffement climatique (t CO éq. /t biomasse)	Impact sur l'épuisement des ressources énergétiques non renouvelables (MJ/t biomasse)	Eutrophisation (g PO_4^{3-} _ /t biomasse**)**
Production des déchets	0	39,5	0
Combustion des déchets	0,889	0	0
Croissance des plantes	- 0,2667	0	2000
Total	0,6223	39,5	2000

Table (13): For oil palm fibres

Etapes de l'analyse du cycle de vie	Impact sur le réchauffement climatique (t CO éq. /t biomasse)	Impact sur l'épuisement des ressources énergétiques non renouvelables (MJ/t biomasse)	Eutrophisation (g PO_4^{3-} /t biomasse**)**
Production des déchets	0	39,5	0
Combustion des déchets	0,895	0	0
Croissance des plantes	- 0,2685	0	1600
Total	0,6265	39,5	1600

Table (14): For sugar cane bagasse

Etapes de l'analyse du cycle de vie	Impact sur le réchauffement climatique (t CO_2 éq. /t biomasse)	Impact sur l'épuisement des ressources énergétiques non renouvelables (MJ/t biomasse)	Eutrophisation (g PO_4^{3-} /t biomasse**)**
Production des déchets	0	39,5	0
Combustion des déchets	0,883	0	0
Croissance des plantes	- 0,2649	0	3000
Total	0,6181	39,5	3000

To reduce our calculated impacts to the production of 1 kWh of electricity in order to allow comparison with those of diesel as suggested by the LCA methodology (same functional unit), the results obtained will be divided respectively by 5231,3953 and 3292 because 1 ton of each of agricultural waste (cocoa cortex, oil palm fibers and sugar cane bagasse) used produces 5231 kWh, 3953 kWh and 3292 kWh respectively. And The impacts linked to the production of 1 kWh of electricity from a generator using diesel are given by **[22].** Then the results become those of the **table** (15) below **:**

Table (15) : comparison of the different environmental impacts of biomass with oil

	Impact sur le réchauffement climatique (kg CO_2 éq. / kWh)	Impact sur l'épuisement des ressources énergétiques non renouvelables (MJ/ kWh)	Eutrophisation (g PO_4^{3-} _ / kWh **)**
Cortex de cacao	0,12	0,007	0,38
Fibres de palmier à huile	0,16	0,010	0,40

Bagasses de canne à sucre	0,19	0,012	0,91
Pétrole	1,01	0,9	0,6

- in terms of impact on global warming
Sugar cane bagasse has the highest value (0.19 (kg CO2 eq. / kWh)) of the 3 wastes. But the waste products (cocoa cortex, oil palm fibre and sugar cane bagasse) have respectively lower impacts (8 times, 6 times and 5 times) than diesel. These 3 agricultural residues are therefore more efficient than diesel.
- impact on the depletion of non-renewable resources
Sugar cane bagasse has the highest value (0.012 (MJ/ kWh)) of the 3 wastes. But the waste products (cocoa cortex, oil palm fibre and sugar cane bagasse) have respectively lower impacts (128 times, 90 times and 75 times) than diesel. So these 3 agricultural residues perform better than diesel. This is because diesel is an exhaustible fossil fuel, whereas the 3 biomasses are renewable resources.
- eutrophication-related impacts
Sugar cane bagasse has the highest value (0.9 (g PO_4^{3-} / kWh)) of the 3 wastes and its impact is even greater than that of diesel (0.6 (g PO_4^{3-} / kWh)). But the 2 other wastes (cocoa cortex and oil palm fibre) have considerable impacts of 0.38 and 0.40 (g PO_4^{3-} / kWh) respectively. This means that P fertilisers are used to grow the raw materials that generate this waste. We therefore need to reduce the use of P and K fertilisers when growing the raw materials that generate this waste.

After analysing the results of the 3 impacts taken into account in this LCA study, it would be advisable to use these 3 agricultural wastes to produce electricity with very good energy and environmental performance instead of fossil fuels (diesel, oil and coal) **[1].**

But there should be sufficient data to take into account the environmental impacts caused by other pollutants such as N_2O, CO, COnV, SO_2, PM_{10} and $PM_{2.5}$. And take into account spatio-temporal discernment and integrate determining local specificities in order to increase the environmental analysis performance of Conventional LCA **[23].**

4. Conclusion and outlook

This study, using LCA with OpenLCA software, could serve as a basis and a tool to help decision-makers (governments, private or public companies, national and international organisations and the general public) in eco-design for the implementation of energy production units (heat and/or electricity) based on the combustion of agricultural residues. This will encourage the creation of a biomass-based energy sector.

This LCA study could in particular allow decision-makers (public and private) to have the necessary information in order to install cogeneration units to produce electricity from these 3 agricultural residues (cocoa cortex, oil palm fiber and sugarcane bagasse) in rural areas which are major producers of raw materials but are often not covered by the electricity grid. Thus, Côte d'Ivoire, the world's largest cocoa producer, could become the first largest producer of electricity from the combustion of cocoa cortex in the boilers of cogeneration units.

References

1. Atta, A.P. Study of the energy and environmental performance of biodiesel for the production of electricity in Côte d'Ivoire (Doctoral dissertation, National Conservatory of Arts and Crafts-CNAM; National Polytechnic Institute Félix Houphouët-Boigny (Yamoussoukro, Côte d'Ivoire) (2017).
2. Baumann, H., et Tillman, A. M. The hitch hiker's guide to LCA (2004).
3. Preacher, K. J., Curran, P. J., & Bauer, D. J. Computational tools for probing interactions in multiple linear regression, multilevel modeling, and latent curve analysis. *Journal of educational and behavioral statistics*, **31**(4), 437-448 (2006).
4. Grøfte, T. H. O. R. B. J. Ø. R. N., Wolthers, T., Jensen, S. A., Møller, N. I. E. L. S., Jørgensen, J. O., Tygstrup, N., ... & Vilstrup, H. Effects of growth hormone and insulin-like growth factor-I singly and in combination on in vivo capacity of urea synthesis, gene expression of urea cycle enzymes, and organ nitrogen contents in rats. *Hepatology*, **25**(4), 964-969 (1997).
5. Belboom, S., & Léonard, A. Environmental impact of the valorization of sugar plants: comparison of first generation biofuels and bioethylene. In Biomass, energy and chemical resource of the future (2012, June).
6. Klöpffer, W. The critical review of life cycle assessment studies according to ISO 14040 and 14044: origin, purpose and practical performance. *The International Journal of Life Cycle Assessment*, **17**, 1087-1093 (2012).

7. Aissani, L., Vaxelaire, S., Papinot, P.-E., Védrine, H., Mollaret, M.-E., Villeneuve, J. Methods assessment of the environmental impacts of waste pre-treatment operations. CleanWasT project (2012).

8. Preacher, K. J., Curran, P. J., & Bauer, D. J. Computational tools for probing interactions in multiple linear regression, multilevel modeling, and latent curve analysis. Journal of educational and behavioral statistics, **31**(4), 437-448 (2006).

9. Christoffersen, L. E. IUCN: A bridge-builder for nature conservation. *Green globe year book*, 59-70 (1997).

10. Brundtland, G. H. Our common future—Call for action. *Environmental conservation*, **14**(4), 291-294 (1987).

11. Aydi, A., Zairi, M., Kallel, A., & Dhia, H. B. Caractérisation de la décharge contrôlée de Jebel Chakir-Tunis (Tunisie). *Techniques Sciences Méthodes***, (5)**, 101-112 (2009).

12. Pelletier, C., Rogaume, Y., Dieckhoff, L., Bardeau, G., Pons, M. N., & Dufour, A Effect of combustion technology and biogenic CO_2 impact factor on global warming potential of wood-to-heat chains. *Applied energy*, **235**, 1381-1388 (2019).

13. Querini, F. Life cycle analysis of alternative energies for the automobile and methodological proposals for a better assessment of local impacts (PhD thesis, ISAE-ENSMA National School of Mechanics and Aerotechnics-Poitiers) (2012).

14. Girard, P., & Sanogo, *O. Combustion and gasification techniques for the recovery of biomass and waste with or without cogeneration. CIRAD-Forest* (2000).

15. Kandel, R. *Global warming*: "*What do I know?"* **No. 3650**. What do I know (2019).

16. Levasseur, A. *Development of a dynamic life cycle analysis method for the assessment of impacts on global warming (Doctoral thesis, Polytechnic School of Montreal)* (2011).

17. Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., ... & Ayres, M. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict?. Canadian journal of forest research, **39**(2), 231-248 (2009).

18. Achten, W. M., Verchot, L., Franken, Y. J., Mathijs, E., Singh, V. P., Aerts, R., & Muys, B. Jatropha bio-diesel production and use. Biomass and bioenergy, **32**(12), 1063-1084. (2008).

19. Queiros, J., Malca, J., & Freire, F. Environmental life-cycle assessment of rapeseed produced in Central Europe: addressing alternative fertilization and management practices. Journal of Cleaner Production, **99**, 266-274 (2015).

20. Piednoir, B. Combustion behavior of biomass residues: demonstration of synergies by mixing in the form of granules (Doctoral dissertation, University of Perpignan) (2017).

21. Oakleaf, J. R., Kennedy, C. M., Baruch-Mordo, S., Gerber, J. S., West, P. C., Johnson, J. A., & Kiesecker, J. Mapping global development potential for renewable energy, fossil fuels, mining and agriculture sectors. *Scientific data*, **6** (1), 101 (2019).

22. Benoist, A., Meneghel Fonseca, L., & Pirot, R. Application of environmental life cycle assessment in West Africa: case study on straight Jatropha oil combustion for electricity generation in Mali (2011).

23. Megange, P. Assessment of environmental impacts by Spatialized Dynamic LCA (Doctoral dissertation, Paris-Saclay University) (2022).