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Research article

An assessment of the renewable energy potential of oil palm residues: A case study of CDC plantation, Cameroon

Ferdinand Ngosong [a,*], Cosmas Ngozichukwu Anyanwu [a,b], Ifeanyi Samson Eze [c]

[a] *Africa Centre of Excellence for Sustainable Power and Energy Development, University of Nigeria, Nsukka, 410001, Enugu State, Nigeria*
[b] *Department of Agricultural and Bio-resources Engineering University of Nigeria, Nsukka, 410001, Enugu State, Nigeria*
[c] *Department of Pure and Industrial Chemistry, University of Nigeria, Nsukka, 410001, Enugu State, Nigeria*

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ABSTRACT

Cameroon faces enormous clean energy accessibility challenges despite abundant energy resources and huge quantities of free oil palm residues (OPR) generated but dumped yearly from the agro-industrial companies like the Cameroon Development Corporation (CDC). Presently, electricity supply is mainly from hydro (73 %) with accessibility of 65 % and 14 % for urban and rural areas respectively, while energy mix is historically dominated by traditional biomass fuels such as firewood and charcoal, accounting for more than 76 % of the country's total energy consumption. The hydro supply is not regular as it depends on weather conditions and this has negatively impacted the economy. The situation is aggravated by the increased energy demand over the past decade as Cameroon has engaged to become an emerging economy by 2035. However, encouraging policies for researchers and investors in the energy sector have been put in place with a view of attaining a 25 % share of renewable energy (RE) by 2035. OPR are a potential (RE) resource but require technical assessment and technological transformation into clean energy rather than dumping, which constitutes a serious environmental problem. This research has assessed the quantity of OPR generated annually at the CDC and estimated its clean energy value from 2004 to 2018 by consulting fruits-harvest records from CDC statistics office and by bomb calorimetry respectively. The significant findings reveal a yearly production of 203666T of OPR with a calorific value of 896 TJ, corresponding to electrical energy potential of 249 MWh. The energy could be used by the industry or injected into the grid to mitigate the current energy challenges.

1. Introduction

Accessibility to reliable, sustainable and affordable energy is determining for the socio-economic development of any country due to its prime role in driving education, health, industrial, commercial and even agricultural activities [1]. In addition, according to the renewable energy map scenario data, there is significant global shift towards clean energy sources with a clear possibility of renewable energy commanding up to two-thirds of world primary energy supply by 2050 [2]. Unfortunately, over 750 million people in the world still live without electricity, and at least 2.6 billion people rely on raw biomass as their main cooking and heating fuel [3]. The situation is even appalling in Sub-Saharan Africa where 83 % of the population currently lack access to clean energy and only 48 % have access

* Corresponding author.
E-mail address: ferdinand.ngosong.pg030@unn.edu.ng (F. Ngosong).

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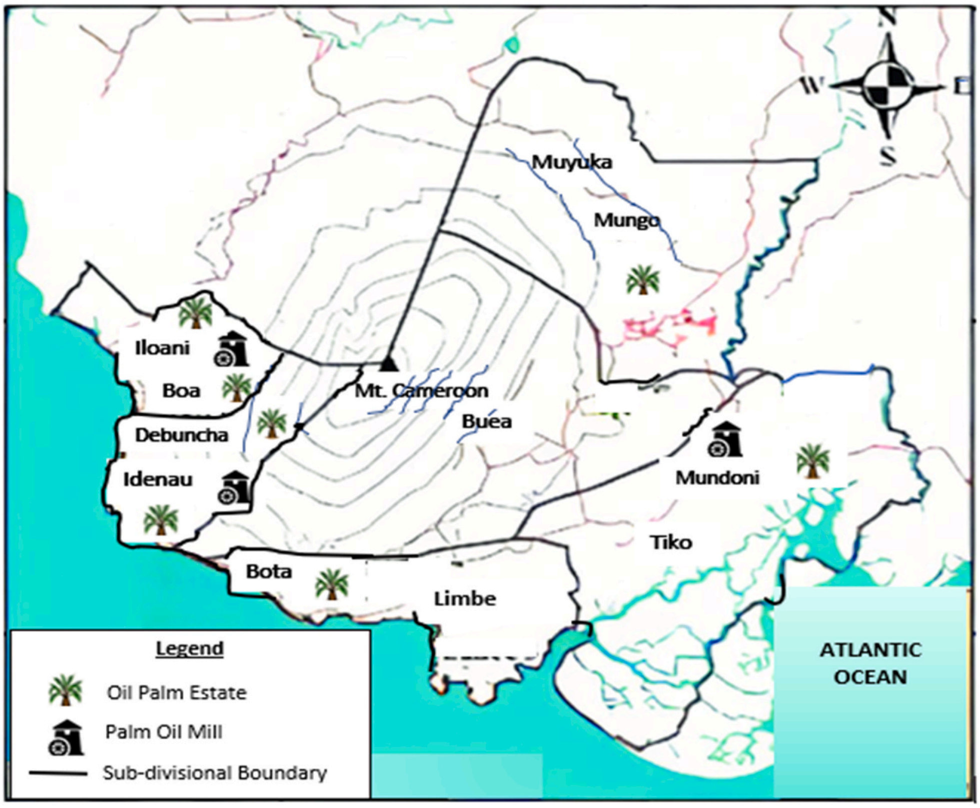
(a)



(b)

Fig. 1. Location of the study area. (a) Map of South West region of Cameroon. (b) Map of CDC oil palm estates and Mills.

to electricity [4] with over 80 % of the population depending on wood, charcoal and crop residues for heating and cooking [5]. Cameroon, a country located in Sub-Saharan Africa with agriculture being the main economic activity due to natural fertile soil, also faces enormous clean energy accessibility challenges despite her abundant energy resources (Hydro, Natural gas, Crude oil, Biomass, Solar and Wind) [6]. Research indicates that over 48 % of her total land surface is covered by forest, while agricultural land increased from 8.03 million ha in 1971 to 9.75 million ha in 2022 growing at an average annual rate of 0.4 % [7]. It is estimated that about 60 million tonnes of different crops are produced annually thus, presenting a huge quantity of agricultural crop residues. Agro-industrial companies like the Cameroon Development Corporation (CDC) created in 1947 have been cultivating oil palms on extensive estates of over 17000ha for crude palm oil production. Even though the CDC palm oil industry satisfies many needs, it negatively impacts the environment with the residues accumulated on the field and palm oil mills over the years of production considering that for every 10 % of oil produced, approximately 90 % [8] residue biomass is generated. Such excessive generation of residues requires significant effort for efficient disposal but there is no available literature on a transformation scheme yet. Common disposal techniques employed include composting and open combustion in the fields which are inefficient and also lead to environmental pollution - emission of Greenhouse gases (GHG) [9].

Electricity supply in Cameroon is mainly from hydro with an estimated accessibility of 65 % and 14 % for urban and rural areas respectively [10], while the energy mix is historically dominated by traditional biomass accounting for more than 74.22 % of the country's total energy consumption followed by petroleum 18.48 % and electricity 7.3 % [11]. This status quo has persisted over decades certainly due to poverty especially in rural areas, increasing population, lack of research to propose suitable solutions at affordable costs, and inappropriate policies. The situation has been exacerbated since 2009 following Cameroon's resolve to become an emerging economy by 2035, which has provoked socioeconomic improvements with a surge in the demand for energy and causing a noticeable higher average demand rate of 6.7 % annually [12]. Considering this sustained demand for energy, the availability of non-competitive oil palm residues and advancements in renewable energy technologies, it therefore becomes imperative to employ sustainable and environment-friendly bio-resource recovery techniques to transform the residues into sustainable energy as a contribution towards achieving the global net-zero goals. Previous research indicates that oil palm residues are highly lignocellulosic hence could be transformed through appropriate technologies into biofuels, sugars, bio-char or animal feed [13]. Bio-char could further be pelletized into pellets for thermal application with the advantage that it is densified, easier to transport and to preserve.

Palm residues are identified, quantified and characterised in Ref. [14]. These residues could be used to produce renewable energy, activated carbon, biofertilizer, and nanocomposites [15]. assessed the bioenergy potential and identified the feasible techniques for processing palm residues in Jalapa, Tabasco, Mexico. It is shown that 564.95 TJ of thermal energy can be recovered from this waste. Also, different techniques of transforming oil palm residues into bioenergy have been evaluated [16], as well as their implementation, and associated challenges [17]. performed energy and cost-benefits analysis of oil palm residues for the production of activated carbon and fertiliser while [18] investigated on the co-production of biochar and electrical energy from oil palm residues in Malaysia.

The quantification of oil palm residues and assessment of its bioenergy potentials is receiving considerable attention in the research communities. However, this has not yet been conducted in CDC palm plantations in Cameroon despite the abundant quantity of residues generated yearly, its negative impact on the environment, its clean energy potential and the present energy challenges in the country. The objective of the present research is to bridge the gap by carrying out an assessment of the sustainable quantity of OPR generated annually from CDC plantations and determining their renewable energy potential (Calorific and Electric energy values). Recent transformation technologies and different value-added products are also established. The present research would therefore create awareness on the annual sustainably available quantity of non-competitive oil palm residues at the CDC plantation and the clean energy potential derivable from it hence, motivate all stakeholders in the sustainable energy sector to exploit it appropriately for the benefit of the industry and local population.

The continuation of this work is divided into the following: Section 2 presents the methodology, section 3 presents the results and discussion, while section 4 presents the conclusion.

2. Methodology

2.1. Geographical location of study area

The present study was carried out in the South-West region of Cameroon, a country in Sub-Saharan Africa, located at the Gulf of Guinea between latitude 2° and 13° N and longitude 8° and 16° E [19]. The country has a wide range of climatic, geographic, vegetation and forest types and the south west region where the CDC plantations are established Fig. 1a–is situated between latitudes.

4.16° and 5.71° N and longitudes 8.9° and 10.06° E. with a surface area of 25410 km^2 [20] and a population of over 1534232 as of 2015. It has the equatorial climate, a 408 km maritime border with the Atlantic Ocean [21] with annual precipitation of 2000–4000 mm and rich volcanic soil [22]. Such natural conditions are very favourable for the Oil palm plantation. The South west region is bordered to the north by the Northwest region, to the east by littoral and West regions, to the west by the Federal Republic of Nigeria and to the south by the Atlantic Ocean. The CDC has seven oil palm estates and three industrial Mills as shown in Fig. 1b.

2.2. Oil palm wastes from CDC plantations

Oil palm wastes were grouped into two: field wastes and Mill or processing wastes.

The field wastes include the oil palm fronds (PF) and oil palm trunk (PT) while the Mill wastes are derived from fresh fruit bunches (FFB) and include oil palm kernel shells (PKS), empty fruit bunches (EFB), the palm mesocarp fibres (MF), and palm oil mill effluent

(POME).

2.2.1. Oil palm fronds

The oil palm fronds as shown in Fig. 2, are obtained during routine pruning to remove dried fronds and to clean the palms or during the harvesting of fruits. A good quantity is also obtained during felling of old and less productive palms to give way for replanting of new and younger palms usually in view of higher yields. Unfortunately, no review has been found on the conversion of these CDC palm residues into more useful forms. They are always abandoned to decompose rather than convert them into some added-value products.

2.2.2. Oil palm trunks

The oil palm trunks are wastes which are produced when the old and less productive palm trees are felled to plant new and younger ones in order to boost yields. Felling is done when the palm trees reach 25–30 years, during which each usually attains an average height that possess harvesting difficulties [23] and the average weight of a 22 year oil palm trunk dry matter is about 344 kg [24]. The PT bagasse contains a considerable amount of starch, cellulose, hemicelluloses, and lignin accounting for about 50 % on a dry weight basis. These are energy rich compounds which render dry PT biomass a good feedstock to produce biofuels [7] rather than abandon to rot (see Fig. 3).

2.2.3. Oil palm empty fruit bunches

The empty fruit bunches shown in figure are wastes generated at the palm oil Mills when fresh fruit bunches are processed and the oil palm fruits extracted for the production of crude palm oil. The abundance of EFB waste has negatively impacted the environment, ranging from fouling, occupation of useful land, attraction of pest, GHG emissions, soil acidification and contamination of underground water [25]. The growing demand for palm oil globally has led to increase in its production and consequently more EFB residue generated.

The current practices of disposing the EFB on the fields for decomposition, dumping by roadsides due to lack of free space (Fig. 4c) or burning (Fig. 5) to reduce volume is first of all a violation of Law No 96/12 of August 5, 1996, relating to Environmental management in Cameroon (the Cameroon Environmental Code) which prohibits dumping of waste without proper treatment.

2.2.4. Oil palm kernel shells (PKS)

The PKS shown in Fig. 6 are solid wastes from the mill obtained when oil is extracted from the fleshy mesocarp then, the central nut is cracked to remove palm seed or kernel which are used to produce palm kernel oil. The shells are burnt at the Mills to heat boilers. This heating method is economical to the industry.

2.2.5. Palm oil mill effluent (POME)

POME is a brownish liquid waste generated from the milling process of fresh oil palm fruits to obtain crude palm oil. It is a mixture of water, palm oil and fine solid suspended particles. As the production of palm oil increases the world over so does the POME waste. It has a high concentration of carbohydrate, protein, nitrogenous compounds, lipids, and minerals, which could be concentrated, and recovered with the aid of ultrafiltration techniques for use as a fermentation medium, fertilizers, and animal feeds or through anaerobic digestion processes to yield methane as biogas [26]. The international campaign on pollution prevention through cleaner

Fig. 2. Oil palm fronds abandoned in fields to decompose.

Fig. 3. Trunks abandoned in field.

(a) (b) (c)

Fig. 4. Empty palm fruit bunches. (a) Fresh EFB, (b) Dry and disposed EFB. (c) EFB dumped by road side.

production based on the so-called 5R policy of reduction, replacement, reuse, recovery, and recycling of wastes encourages companies to transform waste into by-products. POME contains soluble substances like methane, sulphur oxide, ammonia, which are environmentally hazardous especially when they attain certain high concentrations [27] (see Fig. 7).

2.2.6. Oil palm mesocarp fibres (MF)

Mesocarp fibres shown in Fig. 8 are fibrous residue from the mill obtained after pressing the fleshy mesocarp, extraction of palm oil and removing the nuts. However, they still retain some residual palm oil. It is one of the most voluminous solid residues of the oil palm milling process and has also attracted research attention in recent times. In Malaysia for example is has been proven to be a lignocellulosic biomass as well and very rich in fruit fibres, with potential utilization for bio-composite production whereby the fibre can be used to reinforce polymer materials such as thermoplastics [28]. The CDC palm plantation has not yet quantified the MF that it produces because it is mainly considered as a waste even though some fraction is used for heating of boilers.

2.3. Brief overview of transformation technologies of oil palm residues

A brief overview of the OPR transformation technologies and their value-added products for clean energy is summarised in Fig. 9. From the OPR, the different technologies are shown in green while the different types of each technology are in blue and the products are in grey.

2.4. Data collection

Data for this assessment was collected through an interview with personnel of the statistics centre at the Oil palms management

Fig. 5. Pollution from the dumping and burning of EFB at the Idenau Mill site.

Fig. 6. Palm kernel shells.

Fig. 7. Discharge of POME from Idenau oil mill into the environment.

Fig. 8. Pressed mesocarp fibres.

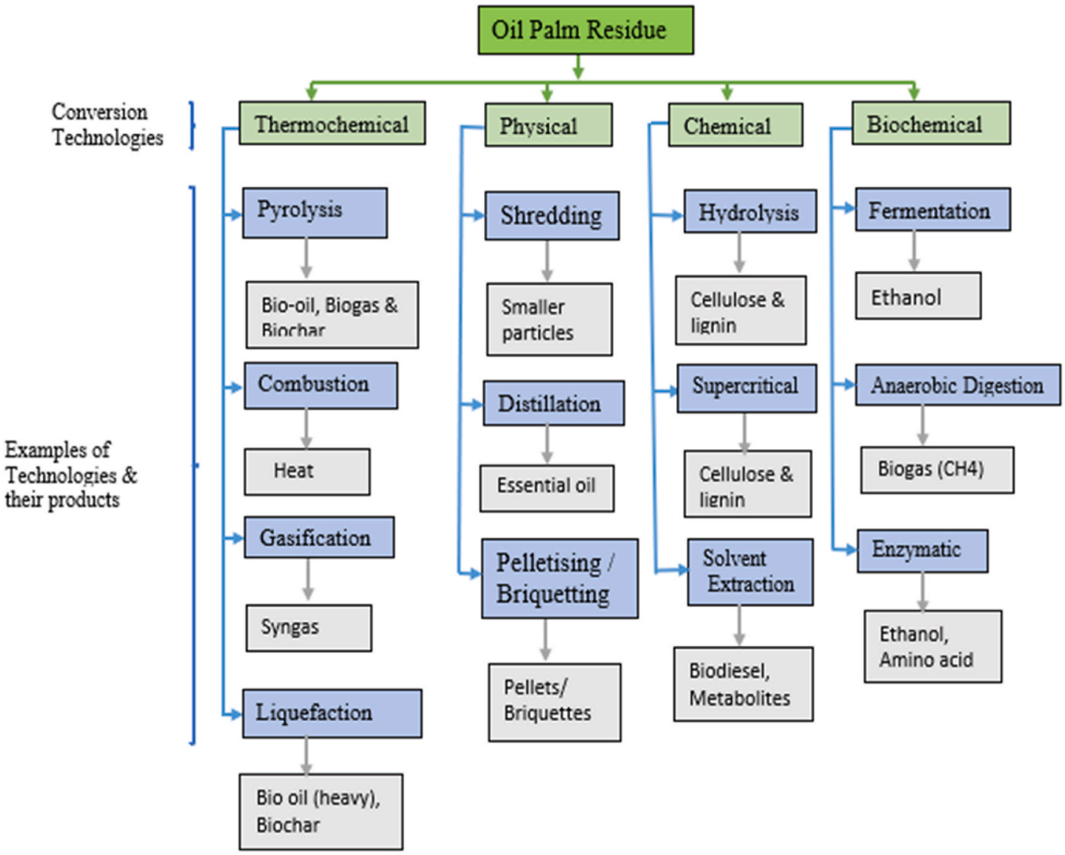


Fig. 9. OPR transformation technologies and value-added products.

department of CDC head office in Bota - Limbe. Questions were related to the size of the plantation, planting density, quantity of fresh fruits harvested per year, the availability of Mills, quantities of different residues generated, and their use or mode of disposal. Available responses were obtained from data records of the past 15 years at the statistics office. For example, upon arrival at the mills, the fresh fruits bunches are quantified and properly recorded so as to determine the ratio of final products (crude palm oil and kernel oil) per estate. The yield of fresh fruit bunches for the period 2004 to 2018 was obtained from records and the data was fundamental for calculating and quantifying palm oil by-products. Given that residues have never been considered useful by the industry, consequently, they have never been quantified. The thermal energy potential of the residues was determined by bomb calorimetry while the corresponding electrical value was determined by calculation.

2.4.1. Quantification of mill residues

Residues from mills had not been quantified because they were considered as wastes. For this research, determination of the quantity of residues from the mills was based on the quantity of FFB recorded and pre-established correlations for calculating the different residues as shown in Table 1 and Table 2.

2.4.2. Quantification of field residues

For the field residues, quantity of fronds produced per year (F_y) was calculated using basic mathematics:

$$F_y = [26P_D \text{ x } A_m] \tag{1}$$

where P_D is planting density and A_m is mature area per year. For CDC, $P_D = 143$ and A_m varies slightly per year as shown in Table 4. The constant 26 represents the average number of fronds pruned per tree per year. On dry weight basis the pruned oil palm fronds were 10.4 t ha^{-1} [34]

The felling factor was not considered because the felling of palms for replanting was found not to be systematic and takes a very long time about 25 years. As a result, trunks residues were not also considered in this research.

2.5. Determination of annual Calorific and Electrical energy values

The Calorific value (CV) in MJ/Kg of each residue was obtained from pre-established measurements using an automated Calorimeter (Model LECO AC-350) and shown in Table 3 [34]. For the detail method, 1g mass of each residue was accurately weighed into the crucible and a nickel fuse wire was stretched between the electrodes ensuring close contact with the residue. 2 ml of water was poured in the bomb to absorb the sulphur and nitrogen from combustion. The bomb was then placed in a weighed quantity of water in the calorimeter and supplied with pure oxygen through the valve to support complete combustion and also displace nitrogen. Then, after gentle stirring and attainment of a steady temperature(T_1), the fuel was fired and new temperature readings recorded after 1/2-min intervals until maximum temperature(T_2) was attained. The heat released by the residue on combustion was absorbed by the surrounding water and the calorimeter. The gross heat of combustion of each residue was calculated using equation (2).

$$CV = C\Delta T - m(e_1 + e_2) \tag{2}$$

Where, C = heat capacity of the bomb calorimeter = 15 kJ/$^{\circ}$C

ΔT = change in temperature

m = mass of residue (g)

e_1 = Correction of heat of formation of sulphuric acid [% of sulphur in sample x 57.54(J/g) x mass of sample (g)]

e_2 = Correction of heat of combustion of fuse wire [length of fuse wire consumed in (cm) x 9.66(J/cm)]

Therefore, the total annual CV for each residue from CDC was obtained as a product of the value kg^{-1} and the total quantity (T) of residue generated per year:

So, $CV_{EFB} = 18.88EFB_T$; $CV_{PF} = 17.72PF_T$; $CV_{PKS} = 20.09PKS_T$; $CV_{PT} = 17.47PT_T$;

$CV_{MF} = 19.05MF_T$; $CV_{POME} = 16.99POME_T$.

Total CV of all residues (CV_{RT}) is:

$$CV_{RT} = \frac{\sum [CV_{EFB} + CV_{PKS} + CV_{MF} + CV_{PF} + CV_{PT} + CV_{POME}]}{6} \tag{3}$$

The electrical energy equivalent was determined by calculation given that basically 1 J of energy per second gives a power of one Watt. That is, $1J^{-s} = 1W$. Therefore 3600J = 1wh.

Table 1
Quantity of Mill residues (Wet basis) generated per ton of FFB processed.

Residue	Quantity generated wet basis (%)	Reference
Empty fruit bunches	20–23	[29–31]
Kernel shells	6–7	
Mesocarp fibres	12–14	
Palm oil mill effluent	60–70	[32,33]

Table 2
Quantity of Mill residues (dry weight basis) generated per ton of FFB processed.

Residue	Quantity generated dry weight basis (%)	Reference
Empty fruit bunches	7.7	[34]
Kernel shells	4.7	
Mesocarp fibres	8.1	
Palm oil mill effluent	Not considered	

Table 3
Calorific values of oil palm residues.

Residue	EFB	PKS	MF	PF	PT	POME
Calorific value (MJ/Kg)	**18.88**	**20.09**	**19.05**	**17.72**	**17.47**	**16.99**

3. Results and discussions

3.1. Results

3.1.1. Annual residues generated

The CDC oil palm plantation has seven estates (Iloani, Boa, Dedundscha, Bota, Idenau, Mondoni and Mungo and three industrial mills (Iloani, Idenau and Mondoni), as shown in Fig. 1b. Information on the mature planted area and quantity of fresh fruits harvested (based on data collected from field as well as the residues generated (based on calculations) for the period from 2004 to 2018 is displayed in Table 4.The results show the quantity of fresh fruit bunches processed at the three CDC Mills and of the different residues generated per year from the Mills. The quantity of palm fronds obtained from field activities during pruning and harvest are also shown as well as the mature planting area from which the fronds were obtained per year for the period 2004 to 2018 corresponding to the study period. The most abundant palm biomass was the oil palm fronds with a quantity of about 30tons (wet basis) and 10.4tons (dry weight basis) per hectare per year, obviously because during harvests and routine pruning, about 26 fronds per tree are cut off each year. For mill residues, about 4tons of POME are produced per hectare each year.

3.1.2. Sustainably available residue per year

The annual sustainably available oil palm residues obtainable from the CDC palm plantation field activities and from the 3 Mills are as summarised in Table 5.

With reference to Table 5, the most sustainably available solid oil palm biomass from the CDC palm plantation Mills is the EFB with a value of 6969tonsyr^{-1} followed by the mesocarp fibres 3666tonsyr^{-1}. These are freely available biomass sources for renewable energy. Calculations of the residue energy values both thermal and electrical were done with reference to Table 3 and the results obtained are shown in Fig. 10.

3.1.3. Thermal and electrical energy potential

PF has the highest energy value because of its huge quantity followed by POME. They are however bulky. The EFB can easily be collected around the Mills and managed.

3.1.4. Challenges in utilizing oil palm residues for biofuel production

Despite the current growing interest of researchers and governments in the circular economy scheme especially reusing non-edible biomass like the OPR for bioenergy, commercial scale utilization still has some challenges. Oil palm residues are second generation feedstock which are bulky, tough (lignocellulosic) and content high moisture of up to 37 % for OPKS and OPEFB causing difficulties in both transportation, particle-size alteration and storage [8]. Time and energy are thus required for drying and a higher loading rate is needed to produce the same amount of energy comparatively with coal. Furthermore, the lower calorific value, and lower density of oil palm residues compared to conventional fuel have also contributed significant drawbacks in utilizing these biomass materials in biomass boilers. However, improvement through pelleting is being employed to densify the biomass. Another challenge is the variability of the oil palm residues, requiring different pre-treatment techniques for transformation and rendering the whole process complex and costly consequently, most of the conversion already obtained are still at Lab scale. Generally, the biomass to electricity conversion efficiency is low and this has led to the development of biomass Combined Heat Power (CHP) systems with proven higher efficiency of about 80 %

3.2. Discussions, policy and practical implications

In this research, the renewable energy potential of OPR from CDC Cameroon have been assessed in view of clean energy generation and in line with the circular economy novelty currently practiced worldwide. Cameroon in her policy has targeted an increase in energy efficiency and a 25 % share of renewable energy in the total generation mix by 2035. The findings of the present research are a

Table 4
Mature planting area, FFB and quantity of Palm residues obtained at CDC from 2004 to 2018.

Item	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MPA (Ha)	14352	14284	14284	13615	13320	11790	10968	10250	10852	11150	12060	12689	12623	13010	12503
FFB (ton)	94452	98257	89311	82925	87718	65427	65687	91558	78916	85410	104259	107735	110224	113205	82788
EFB (ton)	7272	7565	6876	6385	6754	5037	5057	7049	6076	6576	8027	8295	8487	8716	6374
PKS (ton)	4439	4618	4197	3897	4122	3075	3087	4303	3709	4014	4900	5063	5180	5320	3891
MF (ton)	7650	7958	7234	6716	7105	5299	5320	7416	6392	6918	8444	8726	8928	9169	6705
POME (ton)wb	66116	68779	62517	58047	61402	45798	45980	64090	55241	59787	72981	75414	77156	79243	57951
PF (ton)	149260	148553	148553	141596	138528	122616	114067	106600	112860	115960	125424	131965	131279	135304	13001

(MPA = Mature Planting Area, FFB=Fresh fruit bunch, EFB = Empty fruit bunch (dwb), PKS= Palm kernel shells (dwb), MF = Mesocarp fibres (dwb), POME= Palm oil mill effluent, PF= Palm fronds (dwb). [dwb = dry weight basis.

Table 5
Annual average available oil palm residues (tons).

Type	Quantity produced	Quantity used	Quantity available
Oil palm fronds	130173	00	130173
Empty palm fruit bunches	6969	00	6969
Palm kernel shells	4254	4254	00
Palm oil mill effluent	63366.8	00	63366.8
Mesocarp fibres	7332	3666	3666

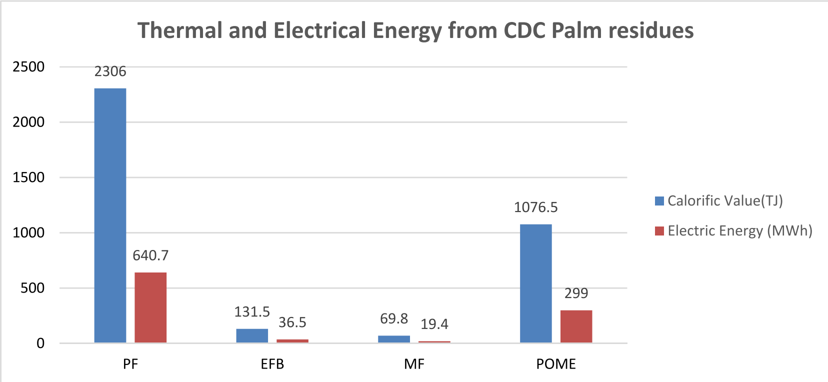


Fig. 10. Annual thermal and electrical energies from CDC available palm residues.

yearly production of 203666T of OPR with a calorific value of 896 TJ and a corresponding electrical energy value of 249 MWh.

Even though these results were obtained through mathematical calculations, the quantity of residues generated reflects the reality on the fields because the quantity of fresh fruits was established from proper recordings obtained at the statistics office of the CDC. On the contrary, from an empirical perspective, the energy values would actually depend on the efficiency of the transformation technology. Thermal energy from 1g of substance is easily contained and measured in a calorimeter but the process of combustion of huge biomass quantities is complex and unstable involving convection, radiations, mass flow which leads to lower efficiency [35]. Also, the value of electrical energy obtained from thermal energy depends on the efficiency of the converting system. According to the International Energy Agency bioenergy report for 2023, the combined heat-power (CHP) plant has very high overall efficiency of 80–90 % because it utilises thermal energy for heating and for power generation compared to about 30–40 % for power generation only [36]. The advantage of the OPR bioresource in this case study lies in its sustainable yearly production and in its abundance.

This availability of abundant biomass resource for clean energy generation at the CDC constitute vital information for all stakeholders, managers and policy makers of the sustainable clean energy sector to exploit appropriately. Following the 2009 decision of becoming an emerging economy by 2035, Cameroon has made enormous efforts to revamp the energy sector. According to the Electricity Sector Regulatory Agency (ARSEL), Cameroon's energy policy targets three major challenges: ensure sufficient, efficient, reliable and clean energy supply; develop and guarantee access to modern energy services; make energy an asset for Cameroonian industry in a global industrial competition. In 2011 the legislature enacted Law N^{o} 2011/022 on the energy sector stating that government shall ensure the promotion and development of rural electrification nationwide with priority given to renewable sources. In addition, surplus electricity generation by independent power producers (IPP) shall be purchased by the electricity transmission system operator or local distributors. The law also states that the state will ensure the promotion and development of renewable energy through establishing regulations for conditions and mechanisms for research, equipment production and project financing. In its National Development Strategy (NDS) 2020–2030 under Rural Electrification Master Plan (REMP), Cameroon targets an additional 3500 MW by 2035 and one million new connections through grid densification/extension and diesel/hydro mini-grids. These encouraging regulations have been put in place to ensure greater exploitation and more energy generation from the various available sources hence, bring about an acceptable increase in energy accessibility in Cameroon. Therefore, it will be an appropriate opportunity for researchers and investors to take advantage of encouraging regulations and the growing demand for clean energy and invest in the Cameroon energy Sector.

Practically, this research brings out prerequisite technical information necessary to activate the transformation process of residues into renewable energy. The transformation which aligns with world trends, will enable Cameroon to simultaneously address climate change, enhance sustainable development, alleviate poverty through employment, improve living standards and stimulate growth in a more human-friendly environment. The huge quantity of OPR generated yearly from the CDC require a commensurate collection and effective utilization scheme. Common practices like composting cannot be a good solution of disposing the abundant residues which are produced because only a very small percentage of it is used and the process duration is long about 180 days [37] to obtain organic manure. Secondly, the rich volcanic soil in the region is very fertile and may not need extra manure. Open combustion which has been practiced as another method of disposal is unhealthy, given that the process emits GHGs which are detrimental to the environment and also lead to global warming [38].

An awareness of the quantity and availability of biomass gives assurance of sustainability and enables proper planning for output energy and loads. Also, the present work would serve as a reference to other researchers who are into the domain and guide policy makers, investors and technicians in taking appropriate decisions in the energy sector to the benefit of the desperately needy.

4. Conclusions

From the present research, it is worthy to note that the CDC palm plantations generates yearly, huge quantities of oil palm residues (203666T) which are available and with current global trends driving towards renewable energy, as well as the developed transformation technologies, they ought to be sustainably utilized for the production of clean energy and mitigate the heavy reliance on fossil fuels. Moreso, Cameroon has undertaken to become an emerging nation by 2035 and the current high energy demand, coupled with good policies on the energy sector including Law N^{o} 2011/022, are encouraging and attractive enough for researchers and investors to take advantage and explore the sector for mutual benefits. This article therefore lays the groundwork for all stakeholders to utilize as guidelines to enable them finetune strategies of getting more involved and contributing practically towards the valorisation of the OPR that are available at the CDC as well as in other oil palm plantations. Transforming the waste as a result of this vital information will go a long way to promote sustainable energy production, improve on human health and healthy environment through proper waste management, create jobs at local level and enforce the utilization of green energy while reducing the use of fossil fuels. These will enhance the achievement of the UN SDG3 (good health and well-being), SDG6 (clean water and sanitation), SDG7 (affordable and clean energy), SDG11 (sustainable cities and communities), SDG12 (responsible consumption and production) and SDG13 (climate action) in Cameroon, Africa and the World by 2030.

CRediT authorship contribution statement

Ferdinand Ngosong: Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cosmas Ngozichukwu Anyanwu:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ifeanyi Samson Eze:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] A.A. Yusuf, et al., A comprehensive review of Liberia's energy scenario: advancing energy access, sustainability, and policy implications, Energy Strategy Rev. 51 (Jan. 2024) 101295.
[2] Q. Hassan, et al., The renewable energy role in the global energy Transformations, Renew. Energy Focus 48 (Mar. 2024) 100545.
[3] B. Diouf, E. Miezan, Unlocking the technology potential for universal access to clean energy in developing countries, Energies 17 (6) (Mar. 2024) 1488.
[4] IEA, World Energy Outlook 2022, IEA, Paris, 2022. https://www.iea.org/reports/world-energy-outlook-2022. License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex B)," 2022.
[5] A.M. Mfokeu, E.V. Chrysostome, J.-P. Gueyie, O.E. Mun Ngapna, Consumer motivation behind the use of ecological charcoal in Cameroon, Sustainability 15 (3) (Jan. 2023) 1749.
[6] R.J. Tanyi, M.S. Adaramola, Bioenergy potential of agricultural crop residues and municipal solid waste in Cameroon, AIMS Energy 11 (1) (2023) 31–46, https://doi.org/10.3934/energy.2023002.
[7] C.D. J, K.S.H. In Yong Eom, Ju Hyun Yu, Efficient Ethanol Production from Dried Oil Palm Trunk Treated by Hydrothermolysis and Subsequent Enzymatic Hydrolysis, 2015.
[8] S. Kaniapan, S. Hassan, H. Ya, K. Patma Nesan, M. Azeem, The utilisation of palm oil and oil palm residues and the related challenges as a sustainable alternative in biofuel, bioenergy, and transportation sector: a review, Sustainability 13 (6) (Mar. 2021) 3110.
[9] Y. Li, R. Gupta, Q. Zhang, S. You, Review of biochar production via crop residue pyrolysis: development and perspectives, Bioresour. Technol. 369 (Feb. 2023) 128423 [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0960852422017564.
[10] N.T. Dieudonné, T.K.F. Armel, A.K.C. Vidal, T. René, Prediction of electrical energy consumption in Cameroon through econometric models, Elec. Power Syst. Res. 210 (Sep. 2022) 108102.
[11] D.K. Kidmo, K. Deli, B. Bogno, Status of renewable energy in Cameroon, Renew. Energy Environ. Sustain 6 (2) (Feb. 2021).
[12] Y. Ayuketah, S. Gyamfi, F.A. Diawuo, A.S. Dagoumas, Power generation expansion pathways: a policy analysis of the Cameroon power system, Energy Strategy Rev. 44 (Nov. 2022) 101004.
[13] R.D.R. Pelaez, M.E.C. Oliveira, R.N.G. Miller, J.R.M. de Almeida, F.G. de Siqueira, Biotechnological valorization of lignocellulosic residues from the oil palm industry: status and perspectives, Biomass Convers. Biorefinery 14 (3) (Feb. 2024) 3077–3099.
[14] M. Jeguirim, B. Khiari, S. Jellali, Identification, Quantification and Characterization of palm-tree and fruit wastes, in: Palm Trees and Fruits Residues, Elsevier, 2023, pp. 1–58.
[15] E.J. Ordoñez-Frías, J.A. Azamar-Barrios, E. Mata-Zayas, O. Silván-Hernández, L. Pampillón-González, Bioenergy potential and technical feasibility assessment of residues from oil palm processing: a case study of Jalapa, Tabasco, Mexico, Biomass Bioenergy 142 (Nov. 2020) 105668.
[16] H.A. Umar, et al., Assessing the implementation levels of oil palm waste conversion methods in Malaysia and the challenges of commercialisation: towards sustainable energy production, Biomass Bioenergy 151 (Aug. 2021) 106179.
[17] K.S. Ukanwa, K. Patchigolla, R. Sakrabani, Energy and economic assessment of mixed palm residue utilisation for production of activated carbon and ash as fertiliser in agriculture, Environ. Technol. 44 (7) (Mar. 2023) 948–960.
[18] G. Su, et al., Co-production of biochar and electricity from oil palm wastes for carbon dioxide mitigation in Malaysia, J. Clean. Prod. 423 (Oct. 2023) 138749.

[19] D.K. Kidmo, K. Deli, B. Bogno, Status of renewable energy in Cameroon, Renew. Energy Environ. Sustain 6 (2) (2021).
[20] Y.N. Etchutakang, F.V. Kewir, D.B. Nde, Postharvest fish processing in the southwest region of Cameroon and the effect of smoke-drying on quality, J. Food Process. Preserv. 2023 (Jun. 2023) 1–13.
[21] E. Muh, S. Amara, F. Tabet, Sustainable energy policies in Cameroon: a holistic overview, Renew. Sustain. Energy Rev. 82 (Feb. 2018) 3420–3429.
[22] C.S. Mbuli, L.N. Fonjong, A.J. Fletcher, Climate change and small farmers' vulnerability to food insecurity in Cameroon, Sustainability 13 (3) (Feb. 2021) 1523.
[23] J.C. Kurnia, S.V. Jangam, S. Akhtar, A.P. Sasmito, A.S. Mujumdar, Advances in biofuel production from oil palm and palm oil processing wastes: a review, Biofuel Res. J. 3 (1) (2016) 332–346, https://doi.org/10.18331/BRJ2016.3.1.3.
[24] Z.Z.Z. Khalid H, A. J. M, Quantification of oil palm biomass and \ nutrient value, A MATURE PLANTATION II (1) (1999) 23–32.
[25] A. Sunday Noah, Oil palm empty fruit bunches (OPEFB) – alternative fibre source for papermaking, in: Elaeis Guineensis, 2022. IntechOpen.
[26] Ifeanyi Charles Okoli, Oil Palm Tree Wastes 8: the Uses of the Palm Oil Mill Effluent, 2020.
[27] M.Z. Salihu, Aliyu and Alam, "Palm oil mill effluent : a waste or a raw material?,", J. Appl. Sci. Res. 8 (1) (2012) 466–473. ISSN 1819-544X.
[28] H.A. Nordin, Noor Ida Amalina Ahamad, Modification of Oil Palm Mesocarp Fiber Characteristics Using Superheated Steam Treatment, 2013.
[29] A. Haryanto, et al., Torréfaction to improve biomass pellet made of oil palm empty fruit bunch, IOP Conf. Ser. Earth Environ. Sci. 749 (1) (May 2021) 012047.
[30] R. Kose, M. Utsumi, H. Yatsui, M. Tun-Abdul-Aziz, T. Okayama, Wettability of the fine fibre sheet prepared from oil palm empty fruit bunches, J. Trop. For. Sci. 30 (4) (Oct. 2018) 546–553.
[31] S.A. Saad, A. Kasim, Gunawarman, "effect of fiber length of the oil palm empty fruit bunch on manufacture particle board with urea formaldehyde adhesive toward the characteristics,", Int. J. Sci. Technol. Res. 7 (11) (2018).
[32] H. Kamyab, S. Chelliapan, M.F.M. Din, S. Rezania, T. Khademi, A. Kumar, Palm oil mill effluent as an environmental pollutant, in: Palm Oil, InTech, 2018.
[33] A. Akhbari, P.K. Kutty, O.C. Chuen, S. Ibrahim, A study of palm oil mill processing and environmental assessment of palm oil mill effluent treatment, Environ. Eng. Res. 25 (2) (Apr. 2019) 212–221.
[34] S.K. Loh, The potential of the Malaysian oil palm biomass as a renewable energy source, Energy Convers. Manag. 141 (Jun. 2017) 285–298.
[35] https://www.ieabioenergyreview.org," Dec. 2023.
[36] https://www.ieabioenergyreview.org, 2023 [Online]. Available:.
[37] F.T.Y. Godwin, A. Monono, Sustainable management and utilization of empty fruit bunches and palm oil mill effluents through composting at the Cameroon development corporation, J. Sci. Technol. 2 (2012) 43–59.
[38] R. Shinde, et al., Management of crop residues with special reference to the on-farm utilization methods: a review, Ind. Crops Prod. 181 (Jul. 2022) 114772 [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0926669022002552.