Cocoa Pod Husks (CPH) as a viable option for the production of Electricity in Ghana

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Declaration of Authorship

"I hereby declare that the presentation submitted is my own unaided work. All direct or indirect sources used are acknowledge as references. This work was not previously presented to another examination board and has not been published."

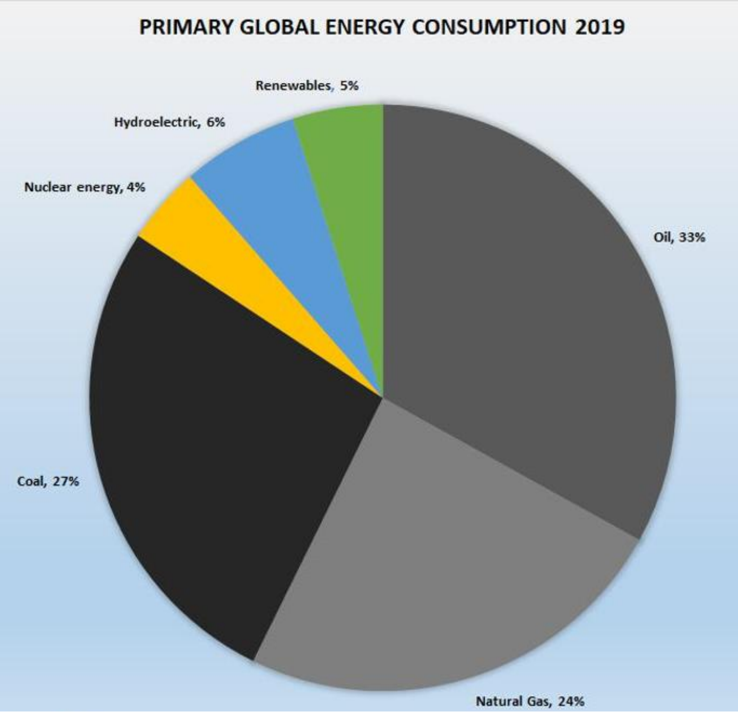
Abstract

Ghana, being the world second largest producer of cocoa bean liberates 858,720 tonnes of Cocoa Pod Husks (CPH) annually after harvest to decompose in farmlands with a small percentage being utilized in potash for soap making, fertilizers and animal feed. Uncontrolled decomposition of these CPH present several environmental challenges and in order to mitigate those challenges, the viability of CPH biomass for electricity generation have been explored and associated with it thermochemical properties.

1.0 Introduction

Generally, the availability and easy access to energy contributes greatly towards the socio-economic development of a country (Maleka, 2016). According to (British Petroleum, 2021), as of 2019, 84% of the world's primary energy consumption came from unstainable fossil fuels as depicted in Figure 1. This has however reportedly contributed to the surge in the greenhouse gas emissions into the atmosphere. In the quest to reduce greenhouse gas emissions coupled with high cost of fossil fuels owing to the rapid depletion of fossil reserves, several researches have brought to light the potentials of renewable biomass as a sustainable energy feedstock (Adjin-Tetteh et al., 2018; Duku et al., 2011).

According to the IEA, biomass refers to ''a range of organic materials recently produced from plants, and animals that feed on the plants'' (IEA, 2007). It has reportedly been the oldest source of energy and used by many, mainly in rural areas of developing countries such as Indonesia and other Sub-Saharan African countries like Ghana, Nigeria, among others (International Energy Agency, 2014; Mohammed et al., 2013; Syamsiro et al., 2012). Biomass comprises of agricultural feed crops, agricultural crop residues and wastes, herbaceous and woody energy crops, aquatic plants, and other materials considered as waste such as some municipal wastes. In Indonesia, 35% of the total national energy consumption comes from biomass which consists mainly of wood waste, rice husks, bagasse, oil palm shell and municipal solid waste (Syamsiro et al., 2012).



(British Petroleum, 2021)

Figure 1. Primary Global Energy Consumption 2019

Though biomass is from agricultural wastes, it is highly convertible into a variety of end products depending on the technology or conversion process used. Energy in the form of electricity or heat production, clean solids, liquid and gaseous fuels, among other several value-added by-product could be obtained from biomass (Maleka, 2016; Ofori-Boateng & Lee, 2013). Numerous studies have proven that, the utilization of biomass as a substitute to fossil fuels for heat and electricity generation reduce drastically the menace of greenhouse gas (GHG) emissions, particularly CO2 since CO2 emitted by biomass combustion makes no net contribution, as it is absorbed by plants, provided the biomass is grown renewably (Maleka, 2016; Nelson et al., 2021). Also, biomass has minimal sulphur concentration as compared to fossils and as a result the emission of SOx during its processed is also minimized.

Cocoa Pod Husk (CPH), which is 70–80% of the dry basis weight of the cocoa fruit (Kley Valladares-Diestra et al., 2022), is one the most expedient source of biomass with diverse potentials due to its constituents (Adjin-Tetteh et al., 2018). Like other plant biomass, it comprises of a mixture of polymers of lignin, cellulose, hemicellulose and a fraction of extractables, which is mainly composed of pectin, proteins, phenolic compounds and some sugars (Kley Valladares-Diestra et al., 2022; Lu et al., 2018). These CPH are readily available in Ghana especially in the rural areas. Ghana is widely known to be one of the world largest producers of cocoa and in the period of 2020 to 2021, it was reported that 1,047 thousand metric tons of cocoa beans were produced (Shahbandeh, 2019). CPH from these cocoa beans are however underutilized and primary used for the production of potash for soap making, fertilizers, animal feed, pectin, biodiesel, among others. In view of this, huge sums of CPH are dump on farm lands causing detrimental effects to the cocoa pod plants, the farmers and the environment at large (Ofori-Boateng & Lee, 2013).

The conversion of CPH to energy has received attention from researchers in recent times due to its thermochemical properties. Several studies have indicated that, it is one of the most effective, sustainable and environmentally friendly way of managing second generational waste from cocoa bean (Maleka, 2016; Nelson et al., 2021). Though bioenergy exists in diverse forms, this paper seeks to focus on the viability of CPH in the generation of electricity to augment Ghana's power grid.

2.0 Case Study

2.1 Cocoa Production in Ghana

Theobroma cacao, commonly known as cocoa is said to have originated from Latin America, nevertheless is now largely cultivated in West Africa. Ivory Coast, Ghana, Nigeria, and Cameroon are noted for being responsible for about 70 percent of total production of Cocoa globally with majority coming from Cote d'Ivoire and Ghana (Dahunsi et al., 2019; Duku et al., 2011). Cocoa being the prevailing and most important export cash crop in Ghana plays a critical role towards the economy of the country. According to (Duku et al., 2011), cocoa production occurs in the forested areas, namely Western, Ashanti, Brong-Ahafo, Central, Eastern region, and Volta

Regions, and covers roughly 1.75 million ha. Locally, cocoa is mainly cultivated for the beans which are used in the production of chocolate, cocoa powder and other similar beverages while the rest of the fruit are discarded. However, the beans constitute of about 33% of the fruit, implying that the cocoa pod husks (CPH) usually discarded after harvest is about 76% of the fruit by weight (Ofori-Boateng & Lee, 2013).

2.2 Cocoa Pod Husk (CPH) Generation

In a report by Nelson et al. (Nelson et al., 2021), Ghana produces about 858,720 tonnes of CPH annually, which is equivalent to 19% of the total global production. These CPH are however left in large piles in farms to decompose causing environmental nuisances such as bad odour, soil contamination, black pod rot disease and serving as medium for transporting pathogenic microorganisms to humans and animals (Duku et al., 2011; Nelson et al., 2020, 2021). Reports have it that 20% to 30% of annual yield loss across the globe is caused by black pod rot, with some farmers experiencing up to 90% loss yearly (Nelson et al., 2021). It is therefore imperative to sort for valuable ways to exploit this abundant biomass (CPH) left on farmlands to benefit the farmers, rural communities and the country at large. The production of bioenergy from these wastes have proven to be an effective way of managing the menaces associated with CPH.

2.3 Alternative Energy

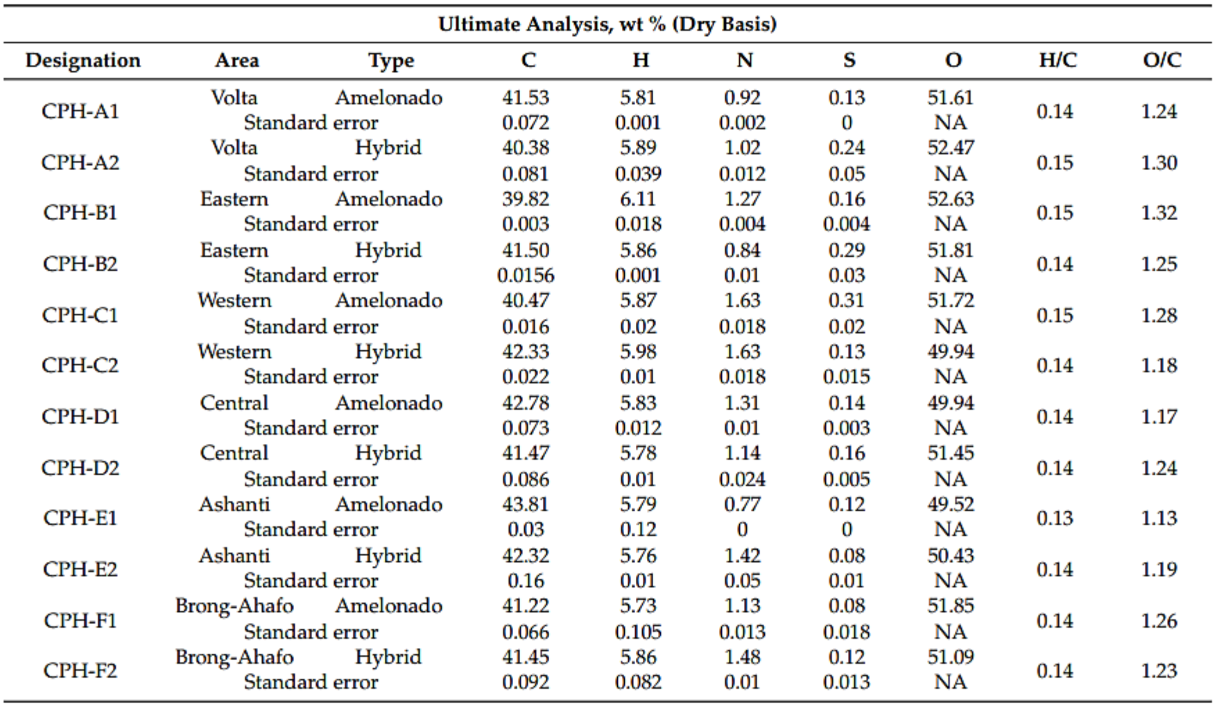
In the year 2019, Ghana appended to the United Nations Sustainable Development Goal (UN SDG) number seven, which is aimed at ensuring universal access to affordable, reliable and modern energy services to all by 2030 (Nelson et al., 2021). The conversion of biomass to bioenergy is one of such sustainable and modern services. Although electricity access rate in Ghana is 84%, the bulk of the electricity is consumed in cities and urban areas and only less than 30% of rural households are grid-connected (Adjin-Tetteh et al., 2018). With the high amount of CPH in most cocoa producing rural areas, it is prudent to use these CPH as a source for energy production. This will not only help mitigate power crisis in the rural areas but also help reduce environmental problems associated with CPH, boost cocoa production and help the country meet its UN SDG 7 target.

3.0 CPH for Electricity Production

3.1 Thermochemical characteristics of cocoa

The potentials or viability of CPHs as a feedstock for power or electricity depends solely on its thermochemical properties. As a result, several studies have conducted proximate and ultimate analysis on partially dried CPH samples from various rural areas in Ghana. In one research conducted by Nelson et al. (Nelson et al., 2021), CPH samples were obtained from six different rural cocoa growing communities in Ghana: Ashanti, Western, Eastern, Brong-Ahafo, Central and Volta regions. The samples were first dried in an oven to achieve a moisture content of about 15% before being crushed using a hammer to obtain a feed size of about 10 millimeters (mm). Proximate and Ultimate analysis were carried out and the results obtained are depicted in tables 1 and 2. The ultimate analysis determines the Carbon, hydrogen, nitrogen, sulphur and Oxygen contents while the proximate analysis determined the moisture, volatile, ash and fixed carbon contents.

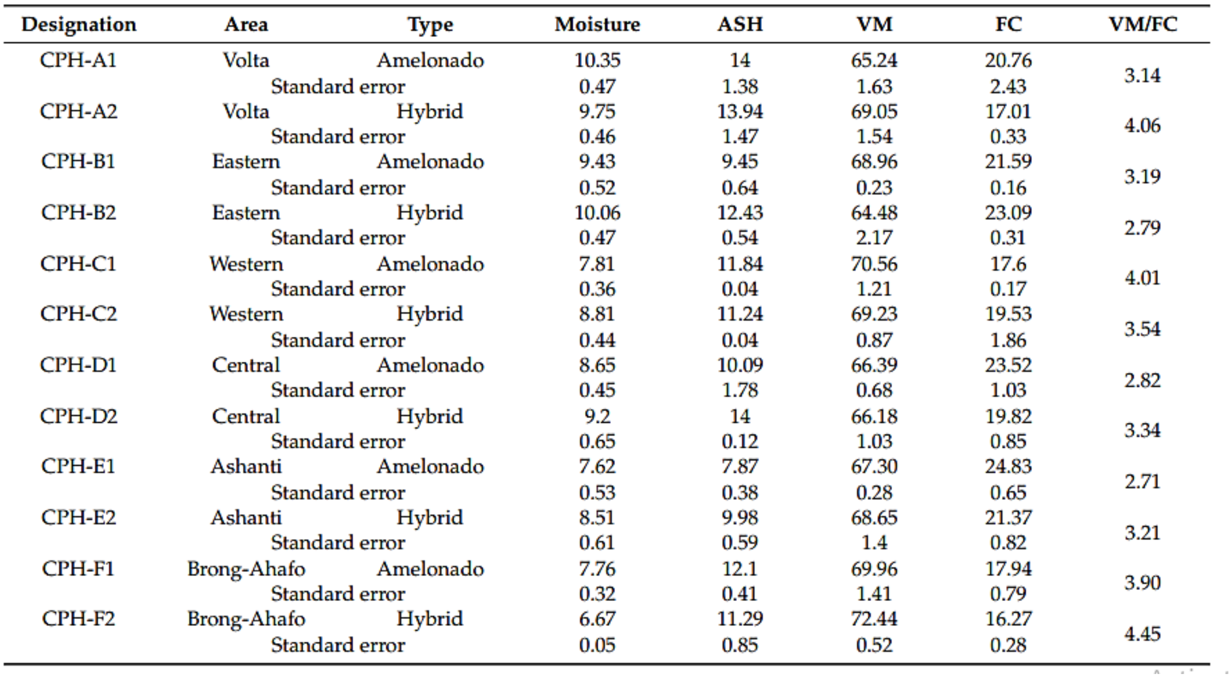
Table 1. Ultimate analysis, wt % (dry basis) of cocoa pod husk (CPH) samples in Ghana



Ultimate Analysis, wt % (Dry Basis)									
Designation	**Area**	**Type**	**C**	**H**	**N**	**S**	**O**	**H/C**	**O/C**
CPH-A1	Volta	Amelonado	41.53	5.81	0.92	0.13	51.61	0.14	1.24
	Standard error		0.072	0.001	0.002	0	NA		
CPH-A2	Volta	Hybrid	40.38	5.89	1.02	0.24	52.47	0.15	1.30
	Standard error		0.081	0.039	0.012	0.05	NA		
CPH-B1	Eastern	Amelonado	39.82	6.11	1.27	0.16	52.63	0.15	1.32
	Standard error		0.003	0.018	0.004	0.004	NA		
CPH-B2	Eastern	Hybrid	41.50	5.86	0.84	0.29	51.81	0.14	1.25
	Standard error		0.0156	0.001	0.01	0.03	NA		
CPH-C1	Western	Amelonado	40.47	5.87	1.63	0.31	51.72	0.15	1.28
	Standard error		0.016	0.02	0.018	0.02	NA		
CPH-C2	Western	Hybrid	42.33	5.98	1.63	0.13	49.94	0.14	1.18
	Standard error		0.022	0.01	0.018	0.015	NA		
CPH-D1	Central	Amelonado	42.78	5.83	1.31	0.14	49.94	0.14	1.17
	Standard error		0.073	0.012	0.01	0.003	NA		
CPH-D2	Central	Hybrid	41.47	5.78	1.14	0.16	51.45	0.14	1.24
	Standard error		0.086	0.01	0.024	0.005	NA		
CPH-E1	Ashanti	Amelonado	43.81	5.79	0.77	0.12	49.52	0.13	1.13
	Standard error		0.03	0.12	0	0	NA		
CPH-E2	Ashanti	Hybrid	42.32	5.76	1.42	0.08	50.43	0.14	1.19
	Standard error		0.16	0.01	0.05	0.01	NA		
CPH-F1	Brong-Ahafo	Amelonado	41.22	5.73	1.13	0.08	51.85	0.14	1.26
	Standard error		0.066	0.105	0.013	0.018	NA		
CPH-F2	Brong-Ahafo	Hybrid	41.45	5.86	1.48	0.12	51.09	0.14	1.23
	Standard error		0.092	0.082	0.01	0.013	NA		

(Nelson et al., 2021)

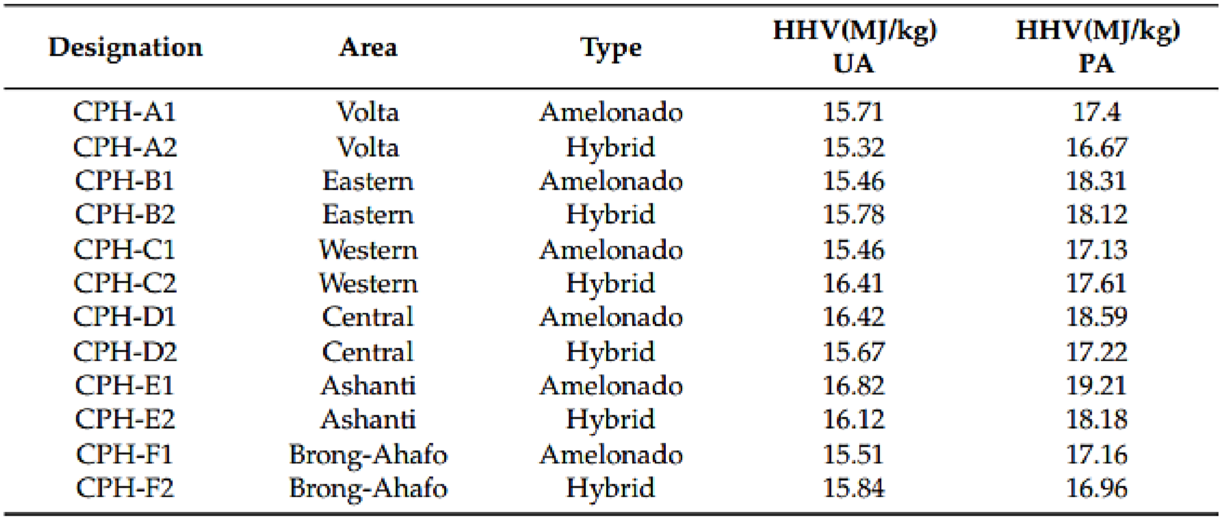
Table 2. Proximate analysis (wt%) of CPH samples in Ghana



Designation	Area	Type	Moisture	ASH	VM	FC	VM/FC
CPH-A1	Volta	Amelonado	10.35	14	65.24	20.76	3.14
	Standard error		0.47	1.38	1.63	2.43	
CPH-A2	Volta	Hybrid	9.75	13.94	69.05	17.01	4.06
	Standard error		0.46	1.47	1.54	0.33	
CPH-B1	Eastern	Amelonado	9.43	9.45	68.96	21.59	3.19
	Standard error		0.52	0.64	0.23	0.16	
CPH-B2	Eastern	Hybrid	10.06	12.43	64.48	23.09	2.79
	Standard error		0.47	0.54	2.17	0.31	
CPH-C1	Western	Amelonado	7.81	11.84	70.56	17.6	4.01
	Standard error		0.36	0.04	1.21	0.17	
CPH-C2	Western	Hybrid	8.81	11.24	69.23	19.53	3.54
	Standard error		0.44	0.04	0.87	1.86	
CPH-D1	Central	Amelonado	8.65	10.09	66.39	23.52	2.82
	Standard error		0.45	1.78	0.68	1.03	
CPH-D2	Central	Hybrid	9.2	14	66.18	19.82	3.34
	Standard error		0.65	0.12	1.03	0.85	
CPH-E1	Ashanti	Amelonado	7.62	7.87	67.30	24.83	2.71
	Standard error		0.53	0.38	0.28	0.65	
CPH-E2	Ashanti	Hybrid	8.51	9.98	68.65	21.37	3.21
	Standard error		0.61	0.59	1.4	0.82	
CPH-F1	Brong-Ahafo	Amelonado	7.76	12.1	69.96	17.94	3.90
	Standard error		0.32	0.41	1.41	0.79	
CPH-F2	Brong-Ahafo	Hybrid	6.67	11.29	72.44	16.27	4.45
	Standard error		0.05	0.85	0.52	0.28	

(Nelson et al., 2021)

Table 3. Higher heating values of CPH by ultimate and proximate analysis



Designation	Area	Type	HHV(MJ/kg) UA	HHV(MJ/kg) PA
CPH-A1	Volta	Amelonado	15.71	17.4
CPH-A2	Volta	Hybrid	15.32	16.67
CPH-B1	Eastern	Amelonado	15.46	18.31
CPH-B2	Eastern	Hybrid	15.78	18.12
CPH-C1	Western	Amelonado	15.46	17.13
CPH-C2	Western	Hybrid	16.41	17.61
CPH-D1	Central	Amelonado	16.42	18.59
CPH-D2	Central	Hybrid	15.67	17.22
CPH-E1	Ashanti	Amelonado	16.82	19.21
CPH-E2	Ashanti	Hybrid	16.12	18.18
CPH-F1	Brong-Ahafo	Amelonado	15.51	17.16
CPH-F2	Brong-Ahafo	Hybrid	15.84	16.96

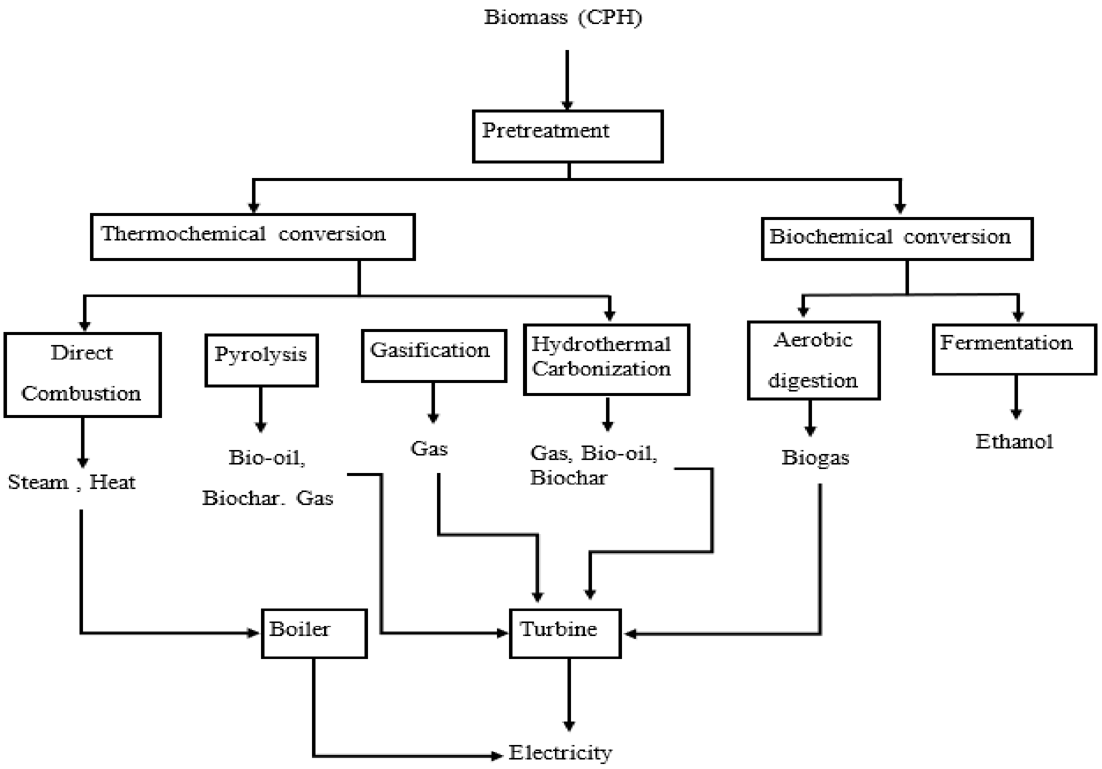
(Nelson et al., 2021)

These data conforms with the results of (Adjin-Tetteh et al., 2018), who estimated the thermochemical characteristics of cocoa pod husks from Effigyase, a town in the Ashanti Region of Ghana and concluded that, the high amount of volatile matter observed was a good indication of better combustibility, gasification and pyrolysis, when used as potential bio-energy feedstock.

3.2 Technology

According to (Maleka, 2016), thermochemical and biochemical processes are the two main process technologies for energy generation from CPH. The thermochemical processes include combustion, pyrolysis, hydrothermal liquefaction, gasification and carbonization whiles the biochemical processes include anaerobic digestion and fermentation (Adjin-Tetteh et al., 2018; Maleka, 2016; Ofori-Boateng et al., 2013). These processes produce three types of primary fuels, that is solids, liquid and gaseous fuels as summarize in Figure 2, that can be converted to electricity, heat or can be used as transportation and cooking fuels, fertilizers, etc. However, the choice of technology depends on a number of factors such as the thermochemical characteristics of the CPH and the moisture content to obtain a high yield. It is known that moisture content has direct impact on the heating value of the CPH. Nevertheless, for thermochemical conversion processes, feedstock's with lower moisture contents is often desired, whereas higher moisture content is often preferred for biochemical conversion processes (Adjin-Tetteh et al., 2018).

Since the moisture content depicted in Table 2 is averagely below 11.07 wt.%, any of the thermochemical methods would be a viable option in generating electricity from CPH. Nevertheless, according to (Nelson et al., 2021), gasification is more appropriate technology for the converting CPH to electricity as compare to combustion and pyrolysis due to its ability to utilize low-quality feedstock and also ability to convert the carbon content of the biomass. Also, biomass gasification can provide a higher heating value product with better energy capture and lower emissions as compared to the other technologies. Thermochemically, CPH to electricity include few stages such as pre-treatment, thermal cracking / combustion and the utilization of the gas or steam to turn turbines and generate electricity.



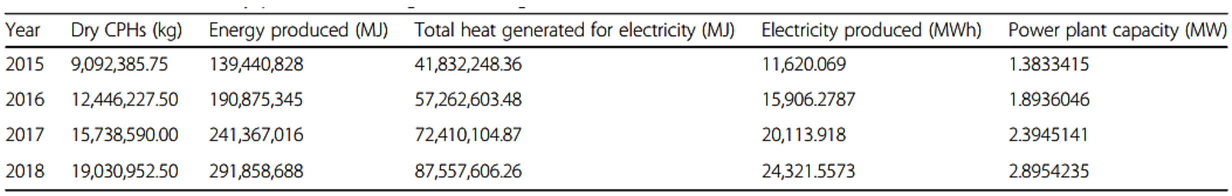
(Maleka, 2016)

Figure 2. Summary of thermochemical and biochemical technologies and their products

3.3 Feasibility

The utilization of CPH as a feedstock for electricity generation have been realized in Uganda according to a study by Kilama et al. (Kilama et al., 2019) with data as seen in Table 4, despite the average calorific value CPH from Uganda being 17.5 MJ/kg.

Table 4. Data on electricity production using CPH in Uganda



Year	Dry CPHs (kg)	Energy produced (MJ)	Total heat generated for electricity (MJ)	Electricity produced (MWh)	Power plant capacity (MW)
2015	9,092,385.75	139,440,828	41,832,248.36	11,620.069	1.3833415
2016	12,446,227.50	190,875,345	57,262,603.48	15,906.2787	1.8936046
2017	15,738,590.00	241,367,016	72,410,104.87	20,113.918	2.3945141
2018	19,030,952.50	291,858,688	87,557,606.26	24,321.5573	2.8954235

(Kilama et al., 2019)

Also, in an economic feasibility study conducted by Maleka (Maleka, 2016) in the generation of electricity from CPH in Côte d'Ivoire (calorific value of 17.9 MJ/kg) via hydrothermal carbonization, for a plant of 14,820.4 kWh/day, the Net present value (NPV), Internal rate or return

(IRR), Payback period (PBT) were 1,866,600.0 USD, 11.42% and 7.03 years respectively. Since the NPV value was positive, it represents that the investment is economically feasible. Also, the payback time was 7.03 years, meaning that such years 100% of the total investment cost will be recovered if the plant is implemented. The higher IRR and the lower PBT imply a less risky investment.

In view of the aforementioned, it can be said that CPH from Ghana with a higher heating value range of 15.32–19.21 MJ/kg coupled with other thermochemical properties is a potential biomass feedstock for generating electricity to serve rural cocoa growing communities.

4.0 Conclusion

In summary, considering the amount of CPH produce in Ghana annually with its thermochemical characteristics, it is a viable and feasible option to convert CPH to bioenergy specifically electricity via thermochemical processes such as direct combustion, pyrolysis, gasification and hydrothermal carbonization. Studies have proven that gasification is a more sustainable, cost effective and environmentally friendly. Hence, the adaption of this technology as a value-added process for the conversion of CPH to electricity would go a long way to reduce the environmental burden associated with CPH and help cocoa growing communities in Ghana obtained affordable electricity for domestic purposes.

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