Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Special Issue: Energy in Agriculture

Review Paper

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v43nepe20220151/2023

POTENTIAL USE OF PALM OIL AND COCOA WASTE BIOMASSES AS SOURCES OF ENERGY GENERATION BY GASIFICATION SYSTEM IN THE STATE OF PARÁ, BRAZIL

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KEYWORDS

biomass gasification, biomass waste, palm oil waste, cocoa waste, energy production.

ABSTRACT

Regional development in the state of Pará (Brazil) continues to be limited by lack of access to energy. This is a problem that is widespread in several rural communities and agricultural regions. Therefore, this study aimed to analyze the potential use of palm oil and cocoa processing waste biomass, which are abundant in the state and whose energy capacities can be used to generate electricity in biomass gasification plants. To do so, a literature review on elementary and calorific value analysis of palm oil (empty fruit bunches, fibers, kernel shell and cake, trunks, and others) and cocoa (pod husks) were conducted. The findings have shown that both waste biomass materials have satisfactory energetic characteristics for use in gasification plants. Thus, palm oil and cocoa processing waste biomasses are alternative energy sources for producers of these fruits in upstate Pará, enabling the development of the region.

INTRODUCTION

Energy, in its various forms and sources, plays an increasingly important role in society and is configured as an indispensable consumer good. Reliance on electric power to achieve sustainable development has been increasing (Philippi Junior & Reis, 2016). The use of biomass for energy purposes has stimulated the agricultural economy and provided an increase in local development (Goldemberg et al., 2008).

Biomass refers to any organic substance from which some type of energy can be obtained, such as mechanical, electrical, or thermal, using agricultural, industrial, forestry, or even urban wastes. Brazil has an excellent capacity to extract organic compounds as a fuel source from biomass materials, which allows a top value in the national scenario (Sousa & Vieira, 2014).

Most energy generation in the Brazilian electricity matrix comes from renewable sources. According to Ben (2021), about 56.8% of internal electricity supply comes from hydraulic sources and 8.2% from biomass materials. Although it occupies fourth place in the electricity generation scenario, most of agribusiness biomass wastes have a purpose other than conversion into electricity. In this line, Atnaw et al. (2014) reported that part of palm oil waste is currently naturally discarded into the soil for decomposition and fertilization purposes. Moreover, Silva (2018) mentioned that one of cocoa residues is used to feed cattle, pigs, poultry, and even fish as dry meal or ensiled.

The use of renewable energy sources is based on a sustainable disposal of organic waste from the agricultural industry. According to Ribeiro et al. (2007), production of agricultural residues in Brazil has been constantly

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Area Editor: Henrique Vieira de Mendonça
Received in: 8-31-2022
Accepted in: 12-6-2022

increasing, mainly due to the growth of the sector, reaching millions of tons annually. The use of such wastes for energy production has been a convenient alternative, solving the environmental problem of waste disposal and on-site power supply (Ribeiro et al., 2007).

According to Coelho & Garcilasso (2018), in most cases, electricity generation systems in agricultural communities consist of diesel generators. A major disadvantage is the price of diesel that has risen in the current Brazilian scenario, increasing transport costs to remote areas. Therefore, small-scale power generation systems that use biomass as a regional fuel source are viable alternatives for local and agricultural development.

Situmorang et. al. (2020) performed a literature review on small power generation systems (<200 kW) in the world and concluded that such technology is promising in North and South Americas due to the amount of waste generated therein. In the north and northeast of Brazil, most communities have no access to an electricity distribution grid. Figure 1 illustrates the isolated electrical systems currently existing in the northern region of the country (EPE, 2022). In this region, the state of Pará has always attracted attention of producers due to its enormous potential for agricultural plantations. Trade in the state is almost exclusively concentrated in the primary sector of industry; however, cocoa and palm oil productions have recently gained prominence, making the state the largest national producer in 2020 (IBGE, 2020).

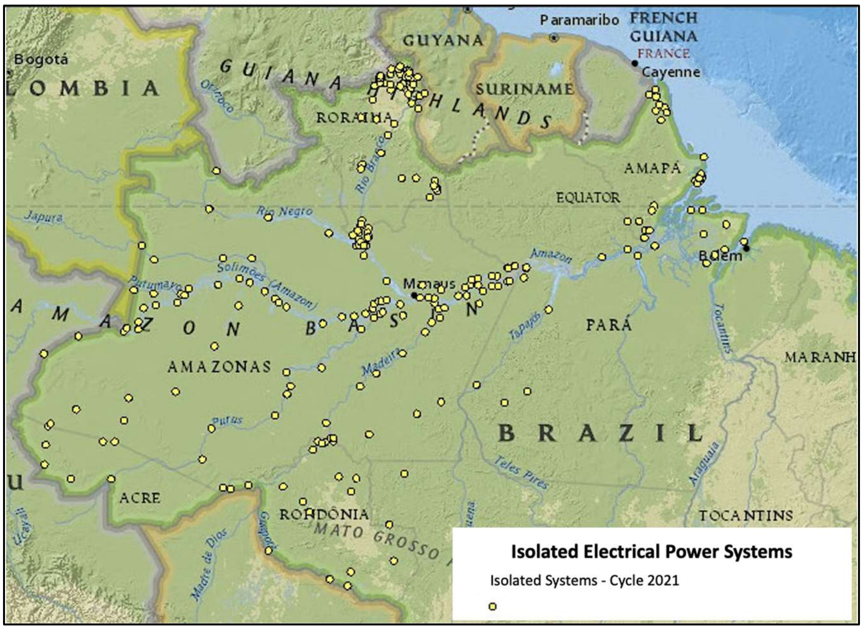


FIGURE 1. Map identifying isolated electricity systems in the Amazon region of Brazil.
Source: EPE (2022)

According to Marçal (2015), palm oil processing generates various by-products such as fibers, bark, almonds, cakes, bunches, and effluents, besides its trunks and oil palm frond can be used as biomass for energy generation. In this sense, the cocoa bean processing industry also produces a significant amount of waste materials. Silva (2018) reported that eight tons of fresh husk are produced for each ton of almond produced in the cocoa industry. Nonetheless, in both cases, most outputs are by-products that are normally discarded.

Kilama et al. (2019) reported that several studies have focused on converting cocoa pod husks (CPH) into new products, such as animal feed manufacturing, potassium extraction, and biomaterials for the food industry. However, the authors stated that only few studies had been published on CPH use as raw material for energy generation until then, citing the works of Syamsiro et al. (2012), Martínez-Ángel et al. (2015), and Maleka (2016). Kilama et al. (2019) also quantified and characterized CPH for electricity generation in remote areas of Uganda with no access to electricity; they confirmed the viability of direct combustion technology and potential of CPH as a raw material for a thermochemical conversion process. Likewise, Dahunsi et al. (2019) investigated the potential of CPH as sources of energy production by anaerobic mono-fermentation to find the best biomass treatment for biogas production.

The British University of Nottingham developed a project to evaluate electricity generation from discarded CPH to benefit farming communities in Ghana (the world's second-largest cocoa producer) with little or no access to grid power. According to the findings, CPH has an energetic potential (from 15.32 to 19.21 MJ/kg) comparable to firewood (about 18 MJ/kg). The CPH content investigated in the study proved to be adequate for thermochemical conversions, such as combustion, gasification, and pyrolysis. Even if combustion, gasification, and pyrolysis are necessary procedures, high ash contents (11.52% on average) can be a barrier to be managed to reduce plant maintenance costs and improve CPH fuel quality and performance (Worall et al., 2020; Nelson et al., 2021).

Zinla et al. (2021) showed that the CPH produced in Ivory Coast (the largest cocoa producer in the world) has a good energy performance and high calorific value (13.7 MJ/kg), Moisture (12.3%), and ash contents (10.8%). However, it has not yet been used for energy purposes in the country. The authors also highlighted a high potassium content (72.05–77.53%) in CPH ashes. Therefore, ashes, which could be an obstacle to the use of CPH for energy generation by gasification, can generate a new co-product for the production of fertilizers, from potassium recovered from ash from thermochemical processing. More recently, Zinla et al. (2022) used life cycle assessment (LCA) to evaluate global warming potential due to electricity production from a biomass plant using CPH from Ivory Coast. The study showed that greenhouse gas (GHE) emissions from electricity generation using CPH are lower than those of generations using fossil fuels.

Given the above, CPH has a high potential for electricity generation by thermochemical conversions such as combustion, gasification, or pyrolysis. In addition to bringing electricity to isolated or poorly connected communities, CPH promotes environmental benefits such as the use of wastes currently discarded in nature, reducing the risk of diseases. Its use in electricity generation also reduces more GHE emissions than fossil fuels. Tailings from the use of CPH, the ashes, can also be used to generate fertilizers, which are now an indispensable raw material for agriculture, an important production sector in Brazil.

Among energy production processes, gasification stands out as a viable alternative for palm oil and cocoa residues in isolated agricultural regions. It converts these organic compounds into a gas mixture rich in carbon oxide and hydrogen. Therefore, biomass gasification is a technological option for palm oil and cocoa producers, as it contributes to social inclusion, the environment, and regional economic development.

Situmorang et. al (2020) summarized biomass gasification systems installed around the world. The authors highlighted that Asian countries, such as China, sell small-scale biomass-gasification power generation systems with capacities from 10 to 160 kW for sawdust and rice husk. In Thailand, they reported that fourteen 5.4-MW biomass gasification plants had been built until 2020. In India, they mentioned one 20-kW generation system in Maharashtra to provide electricity to school and hostel with total 1200 students, two 10-kW gasifiers at the village of Kandhal to provide electricity to 150 people, and one 10-kW system to electrify 100 houses in Thakurwadi. In South America, they noted that despite having great biomass production potential, the countries have a very limited use of this source in small power generation plants with gasifiers. Among them, some small projects are reported in Chile, Argentina, Colombia, and Ecuador, with the latter two building 10-kW prototype projects for biomass gasification. In Argentina, a pilot project for biomass gasification with a capacity of 380 kVA was found. Lastly, gasification, in addition to being a more efficient biomass-gas conversion process than biodigestion, it provides greater thermal efficiency and the gas produced can be used to drive an internal combustion engine.

Mesquita et al. (2022) emphasized the importance of local processing to reuse residues from the extraction of agricultural products in other applications. Among the applications, the authors highlighted energy generation, benefiting the agro-industrial plant, and modernizing the agricultural sector in isolated regions. Therefore, the current study aimed to perform a bibliographic survey on the capacity and potential of cocoa and palm oil waste biomass in gasification systems to produce electricity for consumption by farmers in isolated regions of Pará State, Brazil.

CHARACTERIZATION OF PALM OIL AND COCOA AGROINDUSTRY IN PARÁ STATE

Palm oil agroindustry in the state of Pará

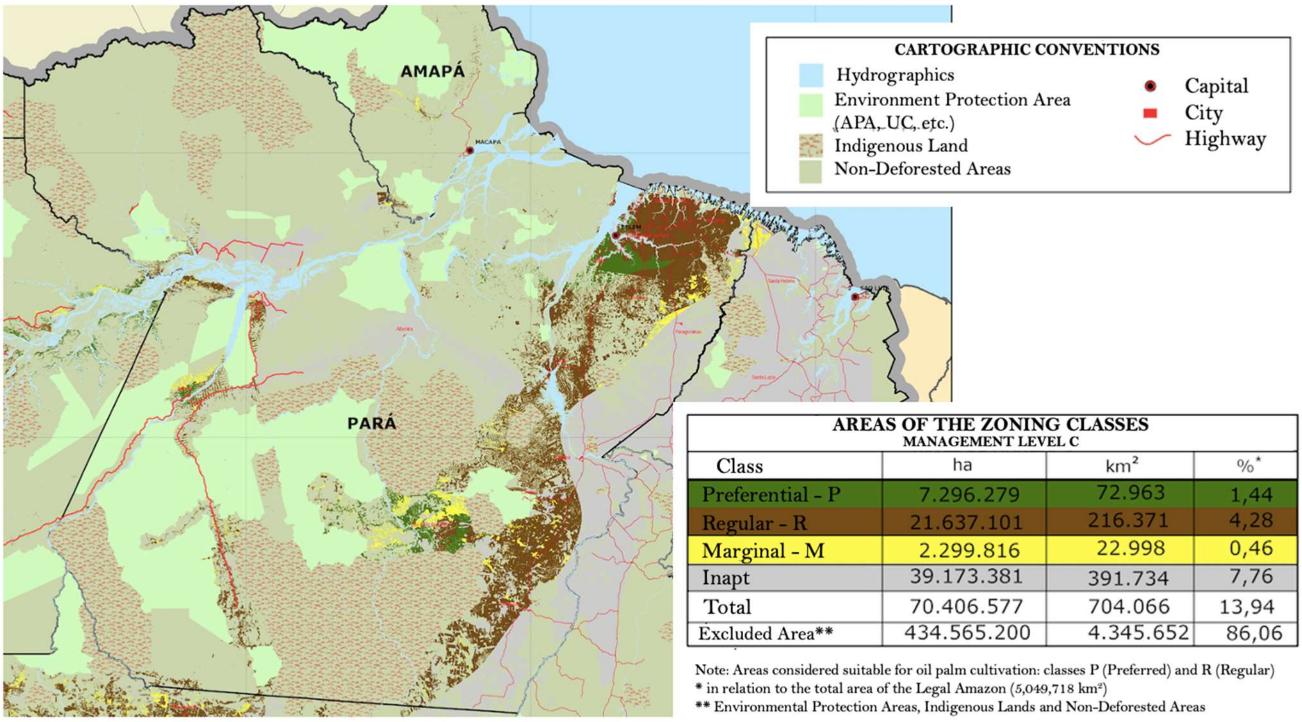
Oil palm is a plant that generates large and heavy bunches filled with small red fruits, from which two oil types are extracted: one (palm oil), which is orange in color, is extracted from fruit pulp; and the other from chestnuts, the so-called palm kernel oil. The first is used in food production (margarine, bread, and ice cream), other industrial applications (soaps, detergents, and natural dyes), and biodiesel production. The second is also used in food manufacture, especially special meals such as biscuits and chocolates, in addition to the cosmetics market (Embrapa, 2014).

According to Embrapa (2015), each ton of palm oil bunches generates about 250 kg of oil, remaining about 220 kg of empty bunches, 120 kg of fibers, 50 kg of barks as residual by-products. These residues are currently used as fertilizers or burned in boilers to generate energy or, as mentioned by Atnaw et al. (2014), naturally discarded into the soil for decomposition and further organic fertilization. Figure 2 illustrates a palm oil plant, its bunches, and fruits.

FIGURE 2. Palm oil.
Source: Liderama (2022)

Expansion of palm oil planting in the Amazon could be an alternative for occupying deforested areas. Therefore, as palm biomass can be a source of energy resources, plantations will promote agricultural and family development, as well as local and regional growth. Embrapa (2022) mapped the areas with greater suitability for palm oil cultivation, which may cover 28.93 million hectares in the state of Pará. Figure 3 illustrates the zoning of land suitability for palm oil cultivation, wherein the regions highlighted in dark green, brown, and yellow and gray (as in the legend) represent more suitable areas, regular areas, and unsuitable areas, respectively.

Pará is a biofuel production hub based on palm oil monocrops. Figure 4 shows the palm oil cultivation areas in northeastern Pará (Silva & Navegantes-Alves, 2017).



Class	ha	km²	%*
Preferential - P	7.296.279	72.963	1,44
Regular - R	21.637.101	216.371	4,28
Marginal - M	2.299.816	22.998	0,46
Inapt	39.173.381	391.734	7,76
Total	70.406.577	704.066	13,94
Excluded Area**	434.565.200	4.345.652	86,06

Note: Areas considered suitable for oil palm cultivation: classes P (Preferred) and R (Regular)
* in relation to the total area of the Legal Amazon (5,049,718 km²)
** Environmental Protection Areas, Indigenous Lands and Non-Deforested Areas

FIGURE 3. Areas with aptitude for palm oil cultivation.
Source: Adapted from Embrapa (2022)

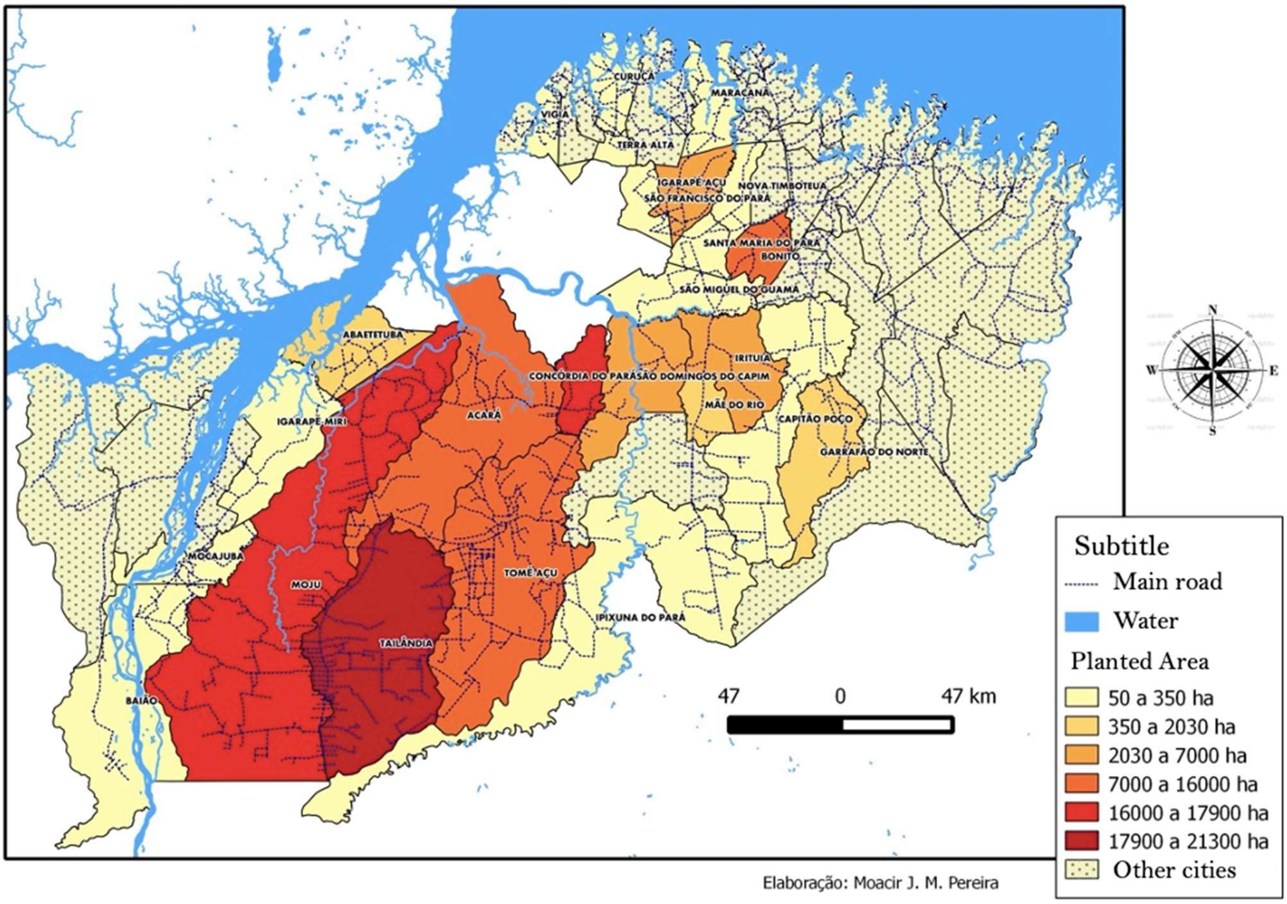


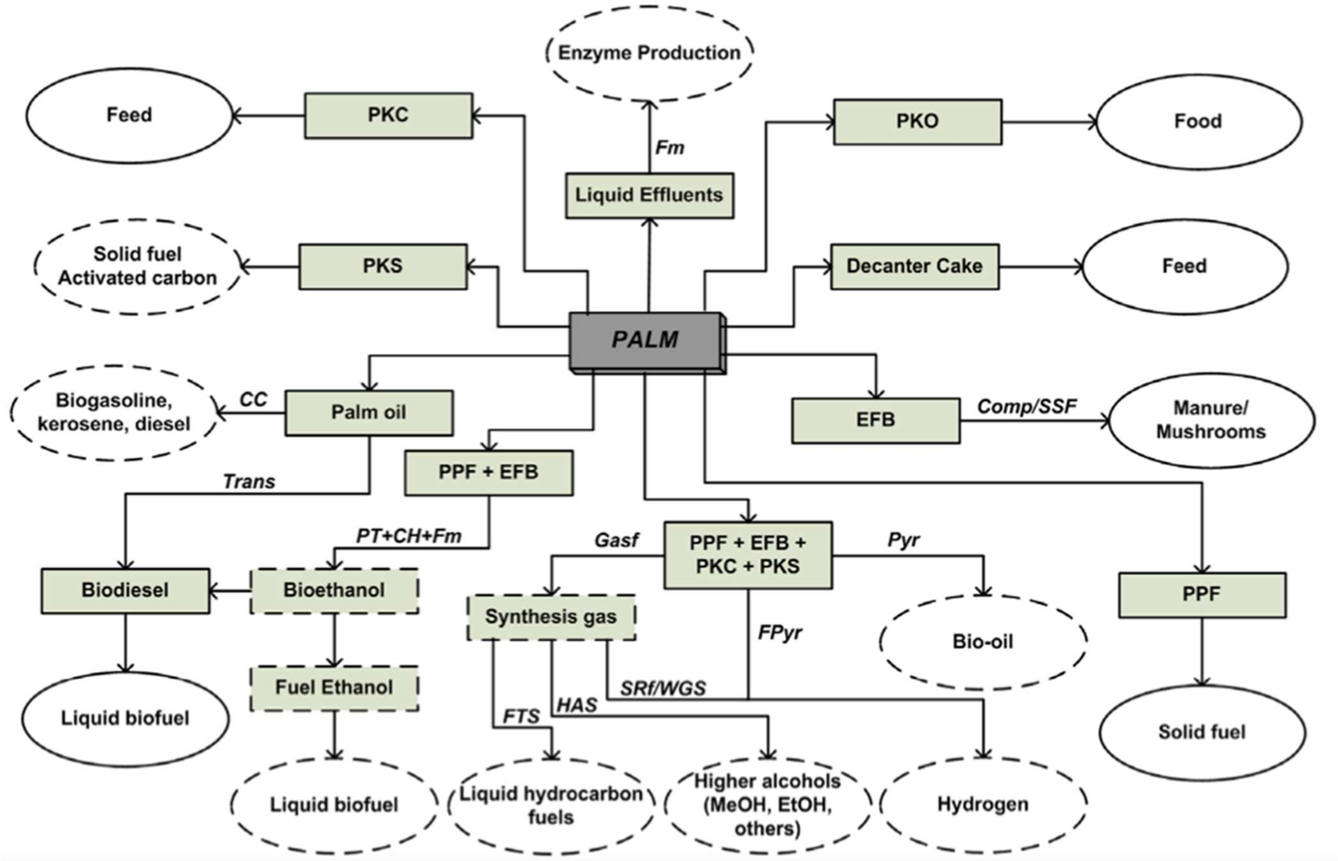
FIGURE 4. Oil plantations in the state of Pará.
Source: Adapted from Silva & Navegantes-Alves (2017)

According to Carvalho (2015), the main producing municipalities are Moju and Tailândia, which have the largest planted areas. Moju has about 68,070 inhabitants, with about 60% of them living in rural areas (Carvalho 2015). Palm oil cultivation in both municipalities is deemed excellent as source of employment and income, because in addition to biodiesel, palm oil is also used for food and cosmetic purposes.

According to Gutiérrez et al. (2009), products, by-products, and biomass of palm oil can be reused. The authors emphasized that bunches are residues at greater quantities and, due to their high Moisture, have been used as fertilizer through composting. Palm kernel cake is a residue from oil extraction produced after chestnut cracking. In addition, fiber from press cake separation, with lower moisture and part of the oil retained, makes it a good solid fuel. Palm kernel shell is another residue generated at a smaller amount than bunches and fiber during palm oil extraction; however, it is a material with high energy value and difficult-to-decompose residue. Figure 5 displays the by-products of palm oil, namely: palm kernel shell and cake, Fibers, and empty bunches.

FIGURE 5. By-products from palm oil processing: (a) Fibers [Source: Piglet et. al (2012)], (b) empty bunches [Source: Benchekchou & Zinebi (2022)], (c) palm kernel cake [Source: Monterrey (2022)], and (d) palm kernel shell [Source: Beston (2022)]

Carvalho (2009) described several by-products from palm oil processing that can be used as fuel, such as biodiesel, bio-gasoline, and kerosene, or even used in food, such as cake (for animal feed) and heart of palm oil (cooking). Figure 6 shows the by-products from palm oil processing. Solid residues, such as palm kernel shell and cake, Fibers, and empty bunches, have high energy power and can be used as a source for gasification processes.



EFB: Bunches of Empty Fruits; PPF - Fibers; PKC - Palmiste cake; PKS - Palm kernel shell; Gasification, Pyr: Pyrolysis, Fpyr: Rapid Pyrolysis, Comp.: Composting, SSF: Simultaneous Saccharification and Fermentation, SRf: Steam Reform, WGS: Gas-Water Displacement Reaction, FTS: Fischer-Tropsch Synthesis, PT: Pretreatment, CH: Cellulose Hydrolysis, Fm: Fermentation, Trans: Transesterification, CC: Catalytic Cracking, HAS: Higher Alcohol Synthesis.

FIGURE 6. Processes arising from the palm.
Source: Gutiérrez (2009)

Cocoa agroindustry in the state of Pará

Cocoa is highly used in the food industry in Brazil and worldwide, generating a large amount of waste with great potential as raw material for energy generation.

According to SENAR (2020), area cultivated with cocoa in the state of Pará is 149,918 hectares, and its production is 145,000 tons of seeds. Also, according to the same source, the main cocoa-producing municipalities in Pará State are: Medicilândia, Uruará, Altamira, Placas, Anapu, Brasil Novo, and Novo Repartimento, which make up the trans-Amazon region; Vale do Xingu and Tucumã, which make up the southern state; and finally, Tomé-Açu, northeastern. Figure 7 illustrates the producing regions with their respective cocoa production hubs in the state of Pará.

Cocoa seed processing generates several by-products that are commonly discarded. If a suitable technology is applied, such waste can be processed into other products of economic importance. Among these residues are CPH, which are broken for seed removal and constitute about 81% of cocoa fruits (Kilama et al., 2019).

According to Figures 3 and 7, palm oil and cocoa have large areas of cultivation. Thus, to process palm oil and cocoa seeds, a large amount of energy is required by boilers, pumps, threshers, macerators, seed and husk dryers, and other processing machine equipment. Therefore, clean energy sources that could be generated from waste of the production chain itself with gasification systems are fundamental.

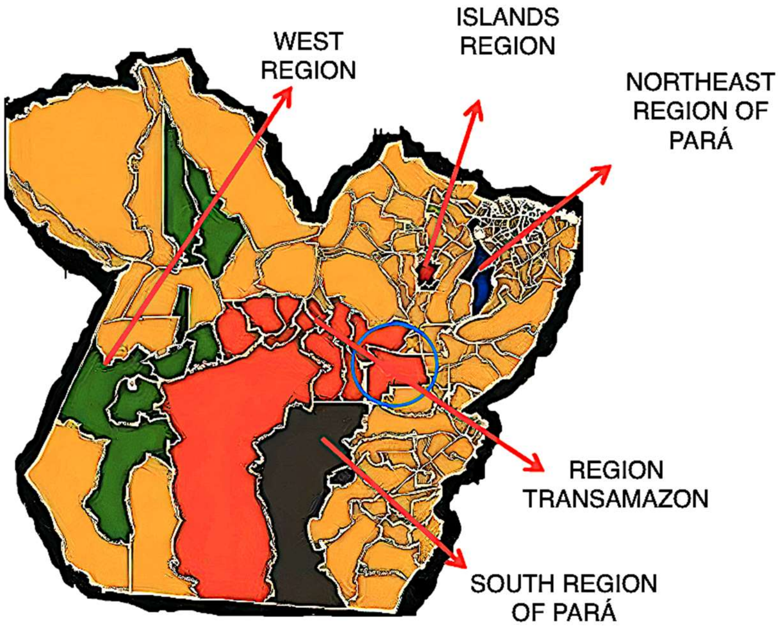


FIGURE 7. Cocoa plantation centers per region in the state of Pará.
Source: Adapted from CEPLAC (2017)

In addition to palm oil and cocoa, small-scale generation units can be used with other biomasses from agricultural products produced in the regions of Pará. Costa (2018) carried out a study highlighting the energy potential of açai seed, coconut shell, corn cob, palm bunch biomasses per region, which can be viable alternatives between harvests, in addition to storing waste pellets for use in gasifiers. Figure 8 illustrates the producing areas of açai seed, coconut shell, corn cob, palm bunch per region by Costa (2018).

GASIFICATION SYSTEM OPERATION

Gasification process consists of partial thermal oxidation, producing a gas composed of various components such as carbon monoxide and dioxide, methane, hydrogen, nitrogen, and hydrocarbons, plus small amounts of coal, ash, and condensable components (e.g., tar and oils). Gas mixture consisting basically of carbon monoxide and hydrogen is generally called synthesis gas, and can be applied for direct burning and hence electricity generation (Balat & Kirtay, 2010).

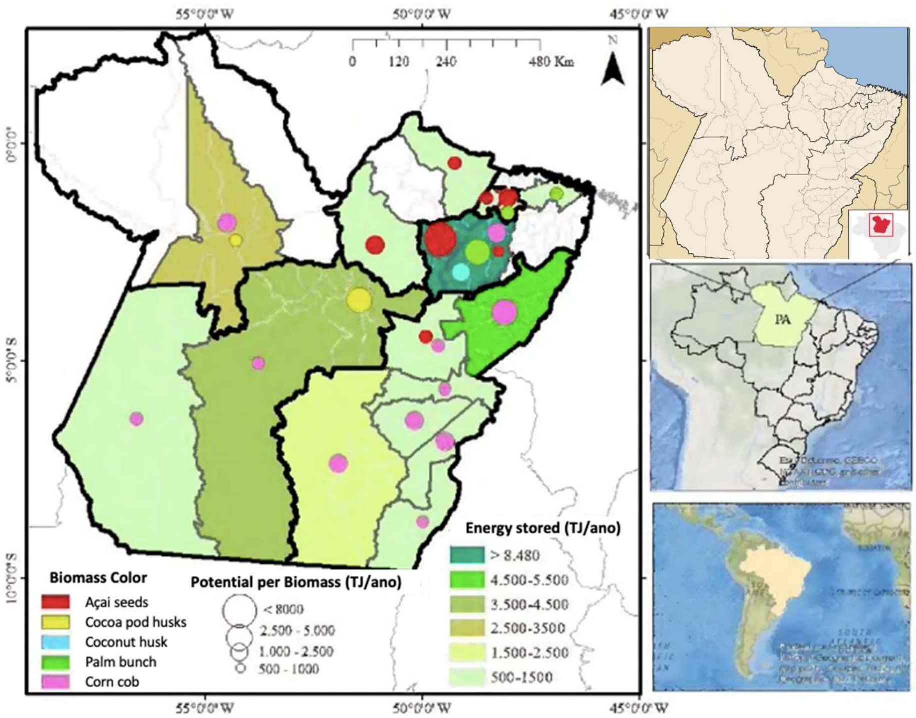


FIGURE 8. Spatial distribution map of açai, cocoa, coconut, palm, and corn residues in the state of Pará in 2016.
Source: Adapted from Costa (2018)

Figure 9 shows that the gas produced from gasification process can be used as an electricity source in gas turbines, machines, or boilers, besides being reused in the production of chemical products and ammonia.

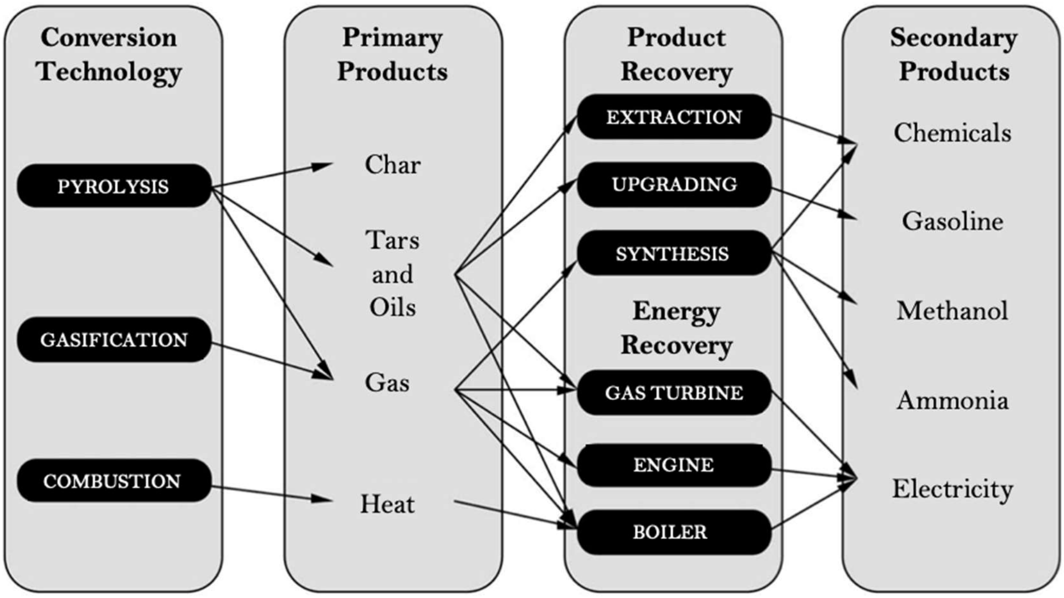


FIGURE 9. Gasification process. Source:
Adapted from Lazarinos (2007).

According to Ribeiro et al. (2007) and Kirubakaran et al. (2009), performance of gasification units depends on the type of biomass, mainly chemical composition, shape, size, and moisture content. Also, according to Ribeiro et al. (2007), synthesis gas produced by the gasifier is an attractive product for the operation of generator sets in small isolated communities.

A gasifier can be considered a reactor that thermochemically converts biomass in to biogas. The literature highlights two main types of gasifiers, namely: fixed and fluidized bed gasifiers. Lazarinos (2007) highlighted the main differences between two gasification reactors (Table 1).

TABLE 1. Main differences between gasifiers.

Countercurrent fixed-bed gasifier with gas recycled	Fluidized bed gasifier
(-) Fines in the feed must be agglomerated.	(+) No problems with fine in the power.
(-) Particle size as uniform as possible.	(+) Wide particle size distribution.
(+) Too large particle sizes (above 100mm).	(+) Limited particle sizes (below 50mm).
(+) Gases virtually free of tars.	(-) Tars (1gr/m3): High levels of tars in gases.
(+) High coal conversion (90 - 99%).	(-) Conversion of coal into beech by 90%.
(+) Discharge of liquid slag.	(-) Fusion of ashes.

(+) Advantages. (-) Disadvantages.
Source: Lazarinos (2007)

Gasification is currently the main technology for converting biomass into energy and a very attractive option for disposing of solid waste from the agroindustry. Fixed bed gasifiers are more suitable for reuse of agro-industry residues, as they maximize use due to large particle sizes and tar-free gases. Figueiredo (2019) studied energy generation by gasification of açai waste in a producing community of Ilha das Cinzas, Gurupá/PA; they observed that the energy generated is enough to meet the demands of the village, thus small generation units can be used in isolated communities. Clean energy production to supply local communities in the Amazon region has become a reality due to biomass gasification. Therefore, energy potential of biomasses must be evaluated in order to replace fossil fuels with renewable sources.

ANALYSIS OF PALM OIL AND COCOA ENERGY POTENTIAL FOR GASIFICATION

Several authors in the literature, such as Fernandes et al. (2013), Protásio (2014), and Costa (2018), have stated that the main characteristics to be mapped in fuels for energy use are: moisture content; calorific value; ash content; volatile materials; fixed carbon; and elemental compositions of carbon (C), nitrogen (N), hydrogen (H), and oxygen (O).

For Costa (2018), moisture content plays a major role in the type of biomass to be used, as it represents the amount of water in material that can be used in thermal conversion such as in gasification. Therefore, low moisture content materials are preferred since a higher moisture may affect combustion, causing low ignition and negatively affecting overall energy balance. Calorific value is another factor and represents the amount of energy in biomass; for Fernandes et al. (2013), it is fundamental for biomass selection, as it directly interferes with energy yield. Regarding volatile materials, Costa (2018) mentioned that it represents the amount of material departing biomass in the form of gas, directly influencing combustion. For Werther et al. (2000), the higher the levels of volatile materials in a fuel, the greater the reactivity, and the easier ignition and burning start. Thus, fixed carbon comprises fuel fraction free of volatile materials, ash, and moisture; therefore, for energy use, biomass should have high levels of fixed carbon. As for ashes, high concentrations reduce biomass calorific value (Costa, 2018). Finally, biomass elementary composition should be analyzed to characterize a biomass for energy use. The analysis consists of determining percentages, in dry mass, of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Protásio et al. (2013) stated that high concentrations of C and H favor energy production since these elements are correlated with calorific value.

Analysis of cocoa energy potential

According to Olayanju et al. (2020), biomass gasification is a process by which agricultural waste is subjected to partial combustion so that biomass undergoes a chemical process to release its gaseous components (e.g., hydrogen, carbon dioxide, and methane) and ashes. Pranolo et al. (2019), Martínez-Ángel et al. (2015), Titiloye et al. (2013), Van der Drift et al. (2001), Kitani et al. (1989), and Syamsiro et al. (2012) performed analyses in CPH for moisture contents, volatile materials, ashes, and fixed carbon, as seen in Table 2. It shows that CPH has contents of volatile materials above 56%, fixed carbon from 10.43 to 32.50%, and ashes between 1.50 and 16.10%.

TABLE 2. Results of moisture, volatile materials, ashes, and fixed carbon analyses for Cocoa pod husks reported in the literature.

Author	Material	Moisture (%)	Volatiles (%)	Ashes (%)	Fixed carbon (%)
Pranolo et al. (2019)	Cocoa pod husk	12.66	60.95	7.97	18.42
			56.00	1.50	32.50
Martínez-Ángel et al. (2015)	Cocoa pod husk	-	68.8	4.10	27.00
			73.7	14.3	12.00
Titiloye et al. (2013)	Cocoa pod husk	10.29	68.47	10.81	10.43
Van der Drift et al. (2001)	Cocoa pod husk	13.90	75.80	10.50	22.90
Kitani et al. (1989)	Cocoa pod husk	-	68.00	8.20	23.80
Syamsiro et al. (2012)	Cocoa pod husk	-	59.5	16.10	22.90

Pranolo et al. (2019), Martínez-Ángel et al. (2015), Titiloye et al. (2013), and Van der Drift et al. (2001) determined the contents of carbon, hydrogen, nitrogen, and oxygen in CPH (Table 3). These authors observed that carbon (C) and oxygen (O) contents in CPH are the highest and may range from 39.87 to 53.00% and from 37.60 to 50.80%, respectively, whereas the contents of hydrogen (H) and nitrogen (N) varied from 5.10 to 6.00% and from 0.50 to 2.20%, respectively.

All authors shown in Tables 2 and 3 presented values referring to an immediate and elementary analysis of CPH. When compared to other biomasses widely used in gasification, such as rice husk, wood, coal, coconut husk, or açai pit, their results showed to be close. Thus, CPH has good conditions to be transformed into biofuel. Moreover, Pereira (2013) emphasized that ashes from thermochemical processes, such as gasification, can be used as mineral fertilizers to the soil due to their concentrations of minerals, especially potassium (K).

TABLE 3. Contents of carbon (C), hydrogen (H), nitrogen (N), and oxygen (O) in the composition of cocoa biomasses reported in the literature.

Author (year)	Material	C (%)	H (%)	N (%)	O (%)
Pranolo et al. (2019)	Cocoa pod husk	39.87	5.96	0.74	45.33
		50.00	6.00	0.70	43.30
Martínez-Ángel et al. (2015)	Cocoa pod husk	43.80	5.20	0.60	50.30
		43.50	5.10	0.50	50.80
Titiloye et al. (2013)	Cocoa pod husk	43.90	5.80	2.20	47.60
Van der Drift et al. (2001)	Cocoa pod husk	53.00	5.85	3.39	37.60

Pranolo et al. (2019), Van de Drift et al. (2001), and Gunasekaran et al. (2021) reported in the literature the averages of calorific value and compositions of gases generated by CPH gasification. Table 4 shows the compositions of C, H, N and O in the CPH biomasses.

TABLE 4. Calorific values and compositions of gases from cocoa biomass gasification.

Author (year)	Material	Calorific value (MJ/kg)	CO (%)	H_2 (%)	N_2 (%)	CO_2 (%)	CH_4(%)
Van der Drift et al. (2001)	Cocoa pod husk	19.30	8.00	9.02	61.45	16.02	2.34
Gunasekaran et al. (2021)	Cocoa pod husk	-	20.30 – 23.80	12.00 – 16.20	-	-	2.30 – 3.20
Pranolo et al. (2019)	Cocoa pod husk	15.5	23.29	13.30	-	14.83	2.66

Note: the values mentioned above may vary with changes in gasifier temperature

The calorific values and composition of gases from CPH in Table 4 are similar to those of other biomasses already used in gasification. This similarity, added to the similarity of findings in the literature and reports in Tables 2, 3, and 4, makes CPH a biomass with potential use for energy generation from gasification.

Analysis of palm oil energy potential

As for palm oil, several residues from products and by-products can be used as power generation sources. Rosa et al. (2016), Ariffin et al. (2016), Lahijani & Zainal (2011), Costa (2018), and Idris et al. (2010) conducted studies in which they considered empty bunches of palm oil as potential biomasses to be used for energy generation. Figure 10 illustrates the empty bunches and fragments used by Ariffin et al. (2016) in a gasifier.

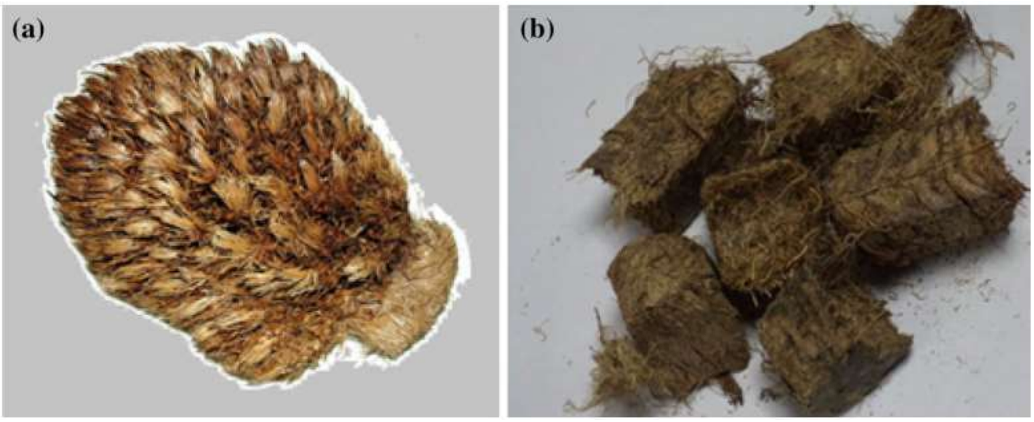


FIGURE 10. Empty bunch (a) and respective fragmentation (b) used in gasifier for energy production.
Source: Ariffin et al. (2016)

Rosa et al. (2016), Ariffin et al. (2016), Ariffin et al. (2015), Guangul et al. (2012), Lahijani & Zainal (2011), Costa (2018), Oliveira (2012), Idris et al. (2010), and Wilson et al. (2011) analyzed moisture content, volatile materials, ashes, and fixed carbon in various residues from palm oil processing (bunches, palm, oil palm frond, trunk, and fibers). All authors observed promising results for using such biomasses in terms of volatile materials (68.80 and 83.50%) and fixed carbon (9 and 18.83%), as seen in Table 5. However, distribution of these elements varies greatly depending on the residue used and palm oil species, as well as the method employed.

The compositions of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) in palm oil residues biomasses were reported in the literature by Ariffin et al. (2016), Ariffin et al. (2015), Guangul et al. (2012), Lahijani & Zainal (2011), Nyakuma et al. (2014), Costa (2018), Oliveira (2012), Wilson et al. (2011), Idris et al. (2010), Luangkiattikhun et al. (2008), as expressed in Table 6. As for carbon, bunches had contents between 41.33 and 48.99%, oil palm frond between 42.88 and 45.60%, fibers between 43.00 and 52.20%, barks 41.33%, and trunks 47.50%. Therefore, regardless of the plant material, C contents in residues were similar in most of the studies cited.

TABLE 5. Results of moisture, volatile materials, ashes, and fixed carbon analyses for palm oil residues reported in the literature.

Author	Material	Moisture (%)	Volatile (%)	Ashes (%)	Fixed carbon (%)
Rosa et al. (2016)	Empty bunches	6.18	72.62	5.27	15.93
Ariffin et al. (2016)	Empty bunches	5.00	83.00	3.00	9.00
Ariffin et al. (2015)	Oil palm frond	6.24	80.23	1.40	18.37
Guangul et al. (2012)	Oil palm frond	16.00	83.50	1.30	15.20
Lahijani & Zainal (2011)	Empty bunches	7.80	79.34	4.50	8.36
Costa (2018)	Empty bunches	10.00	76.63	4.54	18.83
	Empty bunches	-	70.50	5.80	15.40
Idris et al. (2010)	Kernel shell	-	69.20	10.50	16.00
	Mesocarp fiber	-	68.80	10.20	15.20
	Fibers	4.98	79.00	11.80	9.30
Wilson et al. (2011)	Branches	8.10	79.60	7.80	12.60
	Stems	9.10	81.20	3.50	15.30

TABLE 6. Contents of carbon (C), hydrogen (H), nitrogen (N), and oxygen (O) in the composition of palm oil residue biomasses reported in the literature.

Author (year)	Material	C (%)	H (%)	N (%)	O (%)
Ariffin et al. (2016)	Empty bunches	42.08	7.00	0.99	49.93
Ariffin et al. (2015)	Oil palm frond	42.88	7.06	0.52	49.54
Guangul et al. (2012)	Oil palm frond	44.58	4.53	0.71	48.80
Lahijani & Zainal (2011)	Empty bunches	43.52	5.72	1.20	48.90
Nyakuma et al. (2014)	Empty bunches	43.15	5.73	1.20	49.88
Costa (2018)	Empty bunches	48.99	6.61	1.90	36.67
Oliveira (2012)	Fibers	43.00	5.60	1.40	49.80
	Fibers	52.20	7.10	0.70	28.00
Wilson et al. (2011)	Branches	45.60	5.60	0.19	39.30
	Stems	47.50	5.90	0.28	42.50
	Empty bunches	40.93	5.42	1.56	51.78
Idris et al. (2010)	Kernel shell	41.33	4.57	0.99	53.02
	Mesocarp fiber	43.19	5.24	1.59	49.79
Luangkiattikhun et al. (2008)	Fibers	46.64	5.66	1.73	39.46

According to Andrade (2007), the composition of gases generated by palm oil gasification changes with operating conditions (pressure and temperature) and with biomass characteristics (moisture, composition, and oxygen content). CO, H_2, and CH_4 are the main combustible gas components in the gasification gas, as they determine its calorific value. Table 7 shows the compositions of gases generated by gasification of different palm oil residues.

TABLE 7. Composition of gases generated by gasification of different palm oil residues.

Author (year)	Material	Calorific value (MJ/kg)	CO (%)	H_2 (%)	CO_2 (%)	CH_4 (%)
Ariffin et al. (2016)	Empty bunches	16.00	11 – 11.20	5.77 – 7.07	20.63 – 21.81	4.10 – 6.42
Ariffin et al. (2015)	Oil palm frond	17.03	16.31 – 17.62	10.58 – 10.70	17.96 – 18.35	5.97 – 7.40
Guangul et al. (2012)	Oil palm frond	17.28	22.78 – 24.94	8.47 – 10.53	11.81 – 12.80	2.02 – 2.03
Moni and Sulaiman (2013)	Oil palm frond	18.00	9.23 – 28.21	4.71 – 11.29	7.82 – 15.19	4.71 – 11.29

As for the energy capacity of palm oil and cocoa, the elemental and immediate analysis, as well as composition of gases generated and calorific value results were compatible with other materials already used in gasification, such as sawdust, coal, rice husk, sugarcane bagasse, among others. Therefore, biomass from both products can be used as a source of energy in small isolated communities located in upstate of Pará (Brazil).

CONCLUSIONS

Both palm oil and cocoa pod husk biomasses are alternative sources for energy generation in the agricultural sector, as such biomasses have energy capacity and can be used in gasification process for conversion into electrical energy. Biomass gasification is the most efficient to convert palm oil and cocoa pod husk biomasses into electricity, as their elemental compositions are close to other materials already used in this technology. Thus, pilot plants can be made feasible, since the use of these biomasses to generate electricity is justified by their potential for gas generation and their potassium-rich ashes, which can be used to fertilize the soil in the region, in addition to other potential benefits, as generation of jobs and income in rural areas.

In palm oil farms, in addition to processing bunches in mini oil production plants, energy can be generated from wastes (such as oil palm frond, bunches, barks, and trunks), which have been commonly discarded in the vicinity of the rural production area. This energy generation can thus provide local and regional development, modernizing and improving palm oil productivity. Likewise, cocoa producers have cocoa pod husk as an important source of energy generation, adding modernization and development to farms.

Energy generation from agricultural by-products reduces consumption of fossil fuels and emerges as a sustainable alternative with the least ecological impact. In this context, the residues from palm oil and cocoa agro-industries have physical-chemical characteristics with great potential for energy production through gasification process. As reported in the literature, the chemical and gas compositions generated from those residues, together with their amounts generated per year in the state of Pará, make gasification a feasible method for energy production in rural agro-producing areas.

ACKNOWLEDGMENTS

The present study was carried out with the support of the National Academic Cooperation Program in the Amazon (PROCAD/Amazon) and Brazilian Coordination for Improvement of Higher Education Personnel (CAPES/Brazil).

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