Bioenergy and Bio-based Products from the Brazilian Amazon: Social, Economic, and Environmental Aspects

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Abstract There are social-environmental concerns with regard to establishing mechanisms for obtaining certain types of sustainable energy, including resources from the forest and biomass from local agroindustries. Knowledge surrounding the availability and technical application of native waste in the Amazon region allows the promotion of better living conditions for isolated families, especially with increased access to an energy source. This work discusses the potential of the Brazilian Amazon to produce alternative energy sources and considers the related social, economic, and environmental aspects. This section discusses the significance of the main productive resources, including wood, açai, banana, and cassava, as well as their residues, in obtaining bioenergy and bio-based products from biomass. Initially, we present an overview of the region with its general characteristics. Then, we list and identify the opportunities for generating energy to promote sustainable development in the Amazon.

Keywords Amazon biomass · Bioenergy · Native fruits · Public policy · Residues · Rural communities · Sustainability

1 Introduction

The Amazon region, known worldwide as the “lungs of the world,” has a unique biodiversity and is considered an important source of different biomasses. However, there are undeniable social and environmental issues concerning land use, deforestation, and burn areas that have transpired over the last few decades. In recent years, this diverse region, which is located in South America, has drawn attention from
researchers concerning its social and economic concerns. Specifically, the benefits of sustainable usage of natural resources and the exploitation of potential bio-based production [1–3]. Currently, the National Agency of Electricity—ANEEL remains inefficient and unreliable in meeting the requirements of local households and companies. For example, isolated communities must rely on stationary diesel engines, and the use of fossil fuels is often not viable because of the high cost of acquisition and distribution.

However, the use of biomass for renewable and bio-based products offers new hope as generation of waste and biomass is linked to local production. Therefore, cogeneration and biomass are local energy sources that should be considered by rural producers as a method to produce a temporary surplus of electric power during harvest periods. Additionally, good wind, hydrologic, and solar conditions offer other alternative energy sources to small consumers in isolated areas [1].

This chapter discusses alternative methods to produce renewable energy and bio-based products from native waste for small consumers in the Amazon north of Brazil with the aim of achieving sustainable development. First, we provide an overview of the Amazon region, including its territorial division as well as its economic, political, social, and environmental aspects. In the subsequent sections, the main bioproducts from the Amazon are discussed, evaluating their potential to produce bioenergy. Finally, comparing with the alternatives described in literature, we discuss their social and economic effects on rural communities.

2 Literature Review

2.1 Historical Overview and General Aspects

The Amazon biome is comprised of various Amazons where the term “Amazon” is used differently at global and regional levels, though they are interrelated according to their distinct meanings.

Between 1930 and 1945, the Brazilian national government named and classified three regions of the Amazon, assigning them each to an accordant administrative organization to allow for better planning and improved development. They are called the Legal Amazon, International Amazon, and the North Region. Figure 1 presents the characteristics of the three divisions according to [4].

The Amazon Fund, an entity managed by the National Development Bank of Brazil (BNDES), obtains donations for nonrefundable investments in projects that aim to prevent, monitor, and combat deforestation, and promote the conservation and sustainable use of the Legal Amazon. The BNDES also supports systems for monitoring and controlling deforestation throughout Brazil and other tropical countries. This funding is additionally linked to reducing greenhouse gas emissions from deforestation as well forest degradation [5].
The first relevant operation launched by the national government was the Manaus Free Zone, or Zona Franca de Manaus in 1967. It established a free trade area without tax for imported products, such as electronics, automotive, and computer technology industries, in order to boost the regional economy. In 2009, the Green Free Zone (ZFV) was created as a new initiative for regional development through an exemption from the Tax on Industrialized Product (IPI) for products containing a preponderance of regional raw material, vegetable, animal, or mineral origin, or are resultants from extraction, collection, cultivation, or animal breeding [6].

Food industries, pharmaceuticals, leather, and bio-industry hubs have developed bio-based products, such as biocosmetics from native fruits and seeds. Recently, hydroelectric plants, such as the Tucuri and Belo Monte, have been developed to provide relief for energy demands. The Belo Monte has an installed capacity of 11,233 MW and is the fourth largest hydropower plant in the world, although some socio-environmental impacts were incurred during its construction [7].

Organizations such as the Manaus Free Trade Zone Superintendence (SUFRAMA) and the Sustainable Amazon Network (RAS) play important roles in building a regional development model that facilitates the sustainable use natural resources, ensures economic viability, and improves the quality of life of local populations.

However, the Free Zone Model, which has boosted the Amazonian industry in the last decades, must be reevaluated. After more than 50 years, the model has rendered some manufactured products in this region obsolete and stakeholders have indicated a need for innovation in the Amazon industry [8].
Table 1 Socioeconomic profile of North Region compared to National average

| Description                        | North Region   | Brazil         |
|------------------------------------|----------------|----------------|
| Inhabitants—×10³ (2019)            | 18,413 (8.8%)  | 210,147 (100.0%)|
| HDI* (2010)                        | 0.685          | 0.755          |
| GNP**—% (2017)                     | 5.8            | 100.0          |
| Industries—% (2018)                | 3.5            | 100.0          |
| Exportation—% (2019)               | 3.3            | 100.0          |
| Job industry—% (2018)              | 4.2            | 100.0          |
| Average revenue—R$ (2018)          | 2,556.6        | 2,781.2        |
| Electrical tax to industry—R$. MW h⁻¹ (2019) | 660.9          | 649.2          |

*HDI Human development index
**GNP Gross national product; R$: Brazilian real

2.2 Social Aspects in the Amazon

Industrial institutions are concentrated in metropolitan regions, such as Manaus and Belém and less expressively in Acre. These cities are responsible for the highest energy consumption in the region. The quality of life here is different from distant cities and “riverside” communities. Predominantly, city households use diesel and firewood as sources of energy while isolated rural communities mostly depend on stationary diesel engines to generate energy. However, this practice is generally not feasible because of the high cost of fuel and low budget of families [9]. Table 1 shows data according to Report 2017–2019 [10] from CNI—National Confederation of Industry and data from UNDP—United Nations Development Program which relates Human Development Index in Brazil 2010 [11].

According to Table 1, economic development is incompatible with the population size of the North Region compared with the Brazilian average. Economic and social indicators, such as GNP, number of industries, exports, and wage income, reveal the weak economic and social development of the region. Moreover, the high cost of electricity in this region reduces the competitiveness of companies compared with the Brazilian average.

2.3 Consolidated Biofuels Production

The ability to produce so-called conventional biofuels is also a reality in the Amazon Region. These liquid and gaseous fuels have consolidated technologies and are necessary to guarantee the energy supply of local demand. These include biodiesel, biogas, bioethanol, and natural gas for onshore exploitation.

Table 2 compares the participation of the North Region compared with Brazil’s total production last year. Data were obtained from ANP—National Agency of Oil,
Table 2  Comparative energy in Brazilian Amazon Regions in 2019

|                         | North Region | Brazil        | % North/Brazil |
|-------------------------|--------------|---------------|---------------|
| Natural gas a (10^3 m³) | 5571079.0    | 44724232.0    | 12.5          |
| Biogas (Nm³)            | 26579600.0   | 1345000000.0  | 2.0           |
| Biodiesel b—B100 (m³)  | 108280.0     | 5901104.0     | 1.8           |
| Bioethanol c—(m³)      | 241267.0     | 35306997.0    | 0.7           |

aNatural gas is only produced in the North Region by the Amazonas state
bBiodiesel production is reported only in the states of Piauí, Rondônia, Pará, and Tocantins
cTotal ethanol, including anhydrous and hydrated ethanol

Natural gas reserves are being exploited onshore in this region and productive reserves are concentrated in the state of Amazonas, whose capital is Manaus.

Meanwhile, biodiesel has a market share similar to that of biogas in the North Region at 1.8% of Brazilian production. The main sources of biodiesel include beef tallow, jatropha, and, to a lesser extent, cooking oil [14].

Bioethanol is produced from sugarcane, a culture more widely consolidated in the southeast region, especially in the state of São Paulo. In the North Region, bioethanol remains incipient and its production is more intense in Tocantins, a state located closest to the Brazil’s green sugarcane belt.

Alternative electric power sources for the Brazilian Amazon’s remote communities have been studied. The motivation is attributed to the fact that diesel motor is widespread among the population for generating electrical power and for water transportation. It is frequently applied by thousand small boats used for the civil transportation in Amazon rivers. The region concentrates the largest amount of communities living in remote areas [9, 15].

These isolated communities are generally small scattered population groups, typically ranging from 100 to 500 inhabitants (approximately 20–100 families) with poor or nonexistent work conditions. They make up approximately 30% of the region’s population and have no formal occupation. Their survival depends on hunting, fishing, family agriculture, and forest exploitation, and their homes lack electric power, which cannot be economically and technically supplied by neither conventional systems nor the National Interconnected System [9].

2.4 Woody Residues

Residues from the wood industry are largely generated in Amazon Region. Researchers [16] evaluated species of native woods, such as pau-mulato and andiroba and found that their residues are generated from processed wood (board, planks, rafters, clapboard, and joists), laminated wood (blades with various thicknesses and
gauges), plywood (wood, chipboard, and boards), artifacts (frames, wainscoting, floors, doors, windows, leggings, picture frames, pool decks, toys, and kitchen appliances), furniture, and finished products. The average humidity of the residue was 36% and 63% on a wet and dry basis, respectively.

As it is a readily accessed material, dust and chips are residues used by the Triunfo industry in the capital Rio Branco of the state of Acre. Over the next few years, the installed capacity will achieve up to 30 MW. The expected biomass residue is 33 t of wood waste per hour [17].

3 Potential Bioenergy and Bio-based Products from Amazon

3.1 Palm Oil Replacing Fossil Fuels

Some scientists and public services have been developing studies concerning technoeconomic analyses that correlate to the Amazon population’s well-being and biomass generation.

Researchers [18] analyzed the potential biofuel production in degraded lands located in the southeastern Amazon, where most of the deforestation occurred in recent decades. Palm oil was chosen as a technological energy alternative because of its social production structure, environmental benefits, and high productivity. According to its carbon emission coefficient, 16 Mt of palm oil consumption could replace 14.4 Mt of diesel, avoiding 13.1 Mt of carbon dioxide emissions. This palm cultivation could generate 2000–3000 USD/family/year. If employment varied between 200,000 and 300,000 households, the total annual income from palm cultivation could reach approximately 400–900 million dollars, much of which would remain in the region. Furthermore, additional revenue could be generated from different combinations among plantations.

Recently, researchers [3] analyzed the aspects of land-use change from the perspective of sustainability criteria for biofuels. The study showed that palm oil production for energy purposes is very promising to accomplish European biofuel targets. Additionally, there would be a possibility to export palm oil for biodiesel production in Europe in the coming years. Their results reveal carbon stocks calculation does not reflect the diversity of the pastureland where oil palm expansion occurs in the Brazilian Amazon, and demonstrated that palm oil plantations could displace cattle pastures on Amazon frontiers, which can indirectly lead to losses of carbon and biodiversity.
3.2 Native Fungi to Advanced Fuels

Alternatively, bioethanol from lignocellulosic materials has attracted attention as a potential alternative to renewable transportation fuel. One of the most promising routes for the conversion of cellulosic materials into ethanol is enzymatic hydrolysis followed by fermentation. However, the cost of enzymes is still prohibitive [19]. When producing cellulolytic enzymes, a successful strategy includes both microorganism selection and improved fermentation process conditions. In this context, Brazil’s biodiversity enables it to be considered as a potential environment to be searched for microorganisms for such applications because the Amazon biome is the world’s largest reserve of biological diversity, presenting special soil and climate characteristics that are suitable for microorganism growth.

Researchers [20] described the isolation, screening, and selection of biomass-degrading fungi species found in the Amazon forest. Fungal isolates were determined to be efficient producers of cellulase and xylanase. The use of agroindustrial waste (wheat bran, sugarcane bagasse, soybean bran, and orange peel) as substrates for microbial growth was shown to be a promising alternative to produce biofuels from lignocellulosic for large-scale application.

3.3 Açaí Seed as a Bioenergy Source

Açaí (Euterpe oleracea) is one of the main fruit cultures with economic value in the northern region of Brazil, which coincides with the Amazon Region. The edible portion of the palm tree fruit, açaí, is pulp, constituting approximately 32% of the total fruit mass while the remaining 68% is occupied by the seed [21]. The largest producer of açaí is the state of Pará, where 64–90% of its produced volume corresponds to residues generated after agroindustrial processing of the fruit for pulp production [22]. Residues are basically composed of the seed and its attached fibers, which have potential as renewable materials. The proportion between the amount of açaí fruit and its residues is 1.2:1.0 [21].

Açaí seeds have high carbon content (46%) and low sulfur content (0.1%), thereby indicating their potential to produce biochar [23]. Biochar is a porous material rich in carbon that is obtained by the pyrolysis of organic material converted by conditions of low oxygen availability and high temperatures. This bio-based product can be an alternative for isolated communities in the face of deforestation and food insecurity as it has the potential to be used for waste and generate electricity [24].

Açaí trees are manually handled by small family farmers whose composition of forests is not altered. This farming is carried out on a small scale for the subsistence of native families.

The residues from trees were tested as a thermal source for the manufacture of bricks in Imperatriz, a city in Amazonas State [25]. The testing indicated a good potential for combustion (18.6–27.7 MJ kg\(^{-1}\)), thus proving it to be a substitute for firewood with a lower heat potential (18.4 MJ kg\(^{-1}\)). Manufacturing bricks could
be ecologically sound, as it can save time and reduce the volume of waste from açaí extraction. Additionally, the ability to produce briquettes from açaí residue was confirmed by [26]. The positive attributes found included the easy acquisition of residues, local production concentrated at specific sites, reduced costs, and the very promising use as a source of energy in biorefineries.

3.4 Cassava as a Source of Biogas

Cassava (*Manihot esculenta*) is the primary staple food for the majority of indigenous Amazon people because its roots provide carbohydrates after traditional processing [27]. Part of the production of this tuber is intended for the manufacture of flour and other derivatives, such as starch. The cassava crop is interspersed with corn plantations and its cost of production ranges from R$ 0.44 to R$ 0.88 per kg cassava [17].

The residues generated from the industrial processing of cassava have high organic loads and large flows [28]. Researchers [29] reported that in several starchy plants in Colombia, the average generation of wastewater reaches 11,000 L per ton of cassava. The use of biodigesters to produce biogas from cassava residues is another potential application as it is an efficient technology with limited CO₂ emissions. As a result, benefits in soil management and the handling of organic waste products, as well as reducing nitrogen, ammonia, and methane leaching, contribute to the interest in biogas as a source of bioenergy that can replace fossil fuels [30].

3.5 Cupuassu/Cocoa to Bio-based Products

“Cupuaçuzeiro,” also known as cupuassu, (*Theobroma grandiflorum Schum.*) is one of the most important fruit plants in the Amazon due to its participation in production systems. The use of residues from cupuassu pulp extraction remains low because the cupuassu seed or almond has food quality properties. Similar to cocoa, fermented cupuassu seeds can produce chocolate [31].

The cupuassu fruit is 25 cm long and can weigh up to 1.5 kg. The peel and pulp represent 55% and 30% of the total weight, respectively. Each fruit contains approximately 25–50 seeds. One study reported that the cupuassu can be economically and environmentally profitable in producing antioxidant extracts, biofertilizer, biogas, oilseeds, essential oils, ethanol, and bioplastic like polyhydroxybutyrate (PHB) [32].

The residues generated from cupuassu pulp are considered a second-generation raw material and can be used to produce bioethanol, lignocellulosic biomass, and biomolecules with high added value [33].

Cocoa (*Theobroma cacao*) is an Amazon native plant, famous for its fruit, which is used as a raw material for chocolate. In recent years, its production has quadrupled. Planting has been reintroduced in the Amazon region as farmers perceive cocoa plant
growth as a potential for profit. Brazilian producers in Pará have been investing in cocoa as a viable producer of bioethanol through the use of the cocoa pod shell [34].

### 3.6 Banana Peels and Bio-based Potential

The banana is not a fruit native to the Amazon. Regardless, it is produced in the north and comprises an important market share [15]. The state of Pará is the largest producer, accounting for more than 50% of regional production [22].

A banana peel is an important agricultural residue, whose main application in Brazil is as an organic fertilizer. The generation of peels and other fibrous residues from banana processing represents approximately 30% of the raw material [35]. However, some researchers suggest that the production of residues can reach up to 40% [36]. According to the Brazilian Agricultural Research Corporation (Embrapa), for every 100 kg of bananas harvested, 46 kg are not used because they do not meet consumption standards [37].

Although much of the banana produced is consumed naturally, its industrialization represents 2.5–3.0% of national production [36]. Therefore, many studies have proposed an alternative for the reuse of agroindustrial residues that can contribute to the construction of a cyclical economy.

The use of banana peels to produce bioethanol is another form of energy generation that has been widely studied. Ethanol production from banana peels, however, depends on the hydrolysis of carbohydrates, usually formed by a combination of pectinolytic and cellulolytic enzymes. Meanwhile, electricity generation or thermal energy can also be provided by banana residues in timber boilers [38, 39].

Table 3 summarizes works related to potential uses of native plants and fruits in the Amazon.

| Raw materials | Annual production (ton)* | Source of bioenergy | Applications | Authors |
|---------------|--------------------------|---------------------|--------------|---------|
| Açaí          | 204,011                  | The waste, fiber and açaí seeds | Biochar production | [23] |
|               |                          | Açaí waste          | Electricity   | [24] |
| Cassava       | 84,032                   | Wastewater cassava  | Biogas        | [30] |
| Cocoa         | 1,696                    | Lignocellulosic biomass of cocoa pod husk | Bioethanol | [34] |
| Cupuassu      | 3,092                    | Cupuassu fruit      | Biofertilizer, food, biogas | [32] |
| Palm          | –                        | Palm oil            | Biofuel       | [3] |
| Radioactive   | 1,000 kW                 | Sunlight            | Village mini grid (Solar Ice Machines) | [1, 2] |
3.7 Solar Energy

Solar energy has great potential due to the permanent solar incidence in the region. However, it requires governmental incentives because energy costs remain high (see Table 1). For example, for a solar home system in an isolated community (capacity: 0.02–0.10 kW), the typical cost is 0.40–0.60 USD kWh\(^{-1}\), and for a village-scale mini-grid (10–1,000 kW), the cost is approximately 0.25–1.00 USD kWh\(^{-1}\) [1].

Researchers [2] went beyond the use of solar energy to produce only electricity by investigating the implementation of solar ice machines as a way to promote beneficial technologies in isolated communities.

By increasing the participation of hybrid off-grid systems and relying on solar and wind microgeneration with the occasional support of diesel, Brazil would have invested in research regarding storage systems, like hydrogen cells, and small solar panels [1]. The installation of photovoltaic (PV) panels in the Amazon requires an incentive policy. There are several ways to do this, including installation by the government, PV panels in state buildings or municipalities, or private sector investment subsidies to increase the installation of panels [40].

4 Sustainability in the Amazon

When discussing the possibilities of using a biomass energy that is native to the Amazon, there are many economic, social, and environmental aspects that must be considered. First, we must ensure to establish alternative and economically attractive energy from renewable sources, especially in distant regions. In some cases, populations with less availability to energy or accessible technology will need to adapt to new resources.

As discussed by [15], aspects, such as public acceptance, infrastructure limitations, capital shortage, and lack of local technical knowledge at the beginning of project implementation, must be examined. Finally, we must consider the integrated management of bioenergy issues into any land-use plan, including the possibility of intensification of livestock production and the release of land for other productive uses, such as planting productive forests.

Researchers [4] focused on sustainability indicators for bioenergy generation from nonwoody biomass sources in Amazon, which are considered to be modern forms of biomass. They analyzed a list of 29 indicators selected from three system evaluation areas proportionally distributed across environment (11), society (11) and economy (7). The main sustainability attributes found to evaluate the areas were productivity, stability (resilience and reliability), adaptability, equity, and self-reliance. This set of
sustainability criteria helped to guide discussions among the engaged stakeholders involved in enterprising energy generation from native biomass. Schematically, we highlighted the most important aspects and directives in Fig. 2.

5 Final Considerations

Using waste from native biomasses is a valuable way to empower local industry and small communities in the Amazon, especially in isolated areas. The data mentioned in this work showed technical approaches to produce bioenergy and bio-based products for a circular bioeconomy in the Amazon.

We highlighted the local population’s need for power supplies in order to improve their living conditions, and to reduce or overcome poverty conditions while considering both professional and social perspectives. In addition, surplus energy could be generated by small communities, thereby promoting better opportunities for economic development by providing food security and poverty alleviation in rural areas.

Finally, this chapter demonstrates that the diversification of primary energy in the Amazon Region can be achieved with native species. In fact, we believe the integration presented by the seven factors (Fig. 2) can play an important role in guaranteeing sustainable development. In this way, government incentives could provide complex systems, such as biorefineries, food processing units, and waste treatment facilities without disregarding the need for entrainment and education for local families. Although the negative impacts in bioenergy with COVID-19 pandemic—difficulties
in competing with fossil fuels, delays in green transition—we will focus on regional solutions and the creation of new opportunities.

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References

1. Sánchez S, Torres EA, Kalid RA (2015) Renewable energy generation for the rural electrification of isolated communities in the Amazon Region. Renew Sustain Energy Rev 49:278–290
2. Penteado M et al (2019) Among people and artifacts: actor-network theory and the adoption of solar ice machines in the Brazilian Amazon. Energy Res Soc Sci 53:1–9
3. Bicalho T, Bessou C, Pacca SA (2016) Land use change within EU sustainability criteria for biofuels: the case of oil palm expansion in the Brazilian Amazon. Renew Energy 89:588–597
4. Flores JA, Konrad O, Flores CR, Schroder NT (2018) Inventory data on Brazilian Amazon’s non-wood native biomass sources for bioenergy production. Data Brief 20:1935–1941
5. BNDES, National Bank for Economic and Social Development (2020) 2018 Amazon fund activity report. Banco Nacional de Desenvolvimento Econômico e Social, Relatório de Atividades 2018 Fundo Amazônia. www.bndes.gov.br
6. Suframa (2020) Manaus Free Trade Zone Superintendence Superintendência da Zona Franca de Manaus. http://site.suframa.gov.br/
7. Fearnside PM (2019) Hydroelectric plants in the Brazilian Amazon: environmental and social issues. In: Fearnside PM (ed) Hydroelectric plants in the Amazon: environmental and social impacts on decision making on major works, vol 3. INPA, Manaus, pp 7–22 (Hidrelétricas na Amazônia brasileira: Questões ambientais e sociais. In: Hidrelétricas na Amazônia: Impactos Ambientais e Sociais na Tomada de Decisões sobre Grandes Obras)
8. Vieira P (2018) Amazon forum. Exame Magazine, Fórum Amazônia, Revista Exame. https://exame.abril.com.br/economia/atraso-no-parque-industrial-de-manaus-preocupa/
9. Duarte R, Bezerra UH, Tostes MEL, Duarte AM, Rocha Filho GN (2010) A proposal of electrical power supply to Brazilian Amazon remote communities. Biomass Bioenergy 34:1314–1320
10. CNI (2020) National Confederation of Industry. Report 2017–2019 (Confederação Nacional da Indústria, Relatório 2017–2019). http://perfilindustria.portaldindustria.com.br/estado/tudo/pa
11. UNDP Brasil (2020) United Nations Development Program in Brazil. Ranking human development index in Brazil 2010 (Ranking do Índice de Desenvolvimento Humano no Brasil 2010). https://www.br.undp.org/content/brazil/pt/home/idh0/rankings/idhm-uf-2010.html
12. ANP (2019) National agency of petroleum, natural gas and biofuels. Brazilian statistical yearbook of oil, natural gas and biofuels: 2019 (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis). http://www.anp.gov.br/arquivos/central-contenidos/anuario-estatistico/2019/2019-anuario-versao-impressao.pdf
13. CIBIOGÁS (2020) Renewable energy. Biogas map 2019. https://mapbiogas.cibiogas.org/
14. BiodieselBR (2020). List of Biodiesel plants by region: North (Lista de Usinas de Biodiesel por região: Norte). https://www.biodieselbr.com/usinas_brasil/regiones/norte
15. Mendes FB, Delmondes KL, Hassan D, Barros JHT (2019) Economic, social and environmental perspectives on organic residues from Brazilian Amazonian Fruits (Acre). In: Lecture notes in engineering and computer science: Proceedings of the world congress on engineering and
computer science, 22–24 October 2019, San Francisco, USA, pp 33–38. http://www.iaeng.org/publication/WCECS2019

16. Ribeiro EAS (2017) Productive systems, biomass availability and energy attributes of açaí stone and residues from family sawmills in floodplains. PhD dissertation, Graduate Program in Tropical Biodiversity, UFAP, Macapá, AP

17. WWF-Brazil. Executive summary 2016: potential for renewable energy in acre—overcoming the logistical, socioeconomic and environmental challenge (Sumário executivo 2016: Potencial da Energia Renovável no Acre Superando o desafio logístico, socioeconômico e ambiental) [Online]. https://d3nehc6yl9qzo4.cloudfront.net/downloads/potencial_energia_renovavel_no_acre_sumario_executivo.pdf

18. Da Costa RC (2004) Potential for producing bio-fuel in the Amazon deforested areas. Biomass Bioenergy 26(5):405–415

19. Mendes FB, Atala DIP, Thoméo JC (2017) Is cellulase production by solid-state fermentation economically attractive for the second generation ethanol production? Renew Energy 114:525–533

20. da Delabona PS, Pirotta RDPB, Codima CA, Tremacoldi CR, Rodrigues A, Farinas CS (2012) Using Amazon forest fungi and agricultural residues as a strategy to produce cellulolytic enzymes. Biomass Bioenergy 37:243–250

21. de Arruda JCB et al (2018) Açaí seed bran in the feed of slow-growth broilers. Acta Amazonica 48(4):298–303

22. IBGE (2018) Brazilian Institute of Geography and Statistics—IBGE Census (Instituto Brasileiro de Geografia e Estatística - Censo IBGE). https://www.ibge.gov.br/estatisticas-novoportal/economicas/agricultura-e-pecuaria/9105-producao-da-extracao-vegetal-e-dasilvicultura.html?r=-&t=resultados

23. Sato MK et al (2020) Biochar as a sustainable alternative to açaí waste disposal in Amazon, Brazil. Process Saf Environ Prot 139:36–46

24. Teixeira MA, Escobar Palacio JC, Sotomonte CR, Silva Lora EE, Venturini OJ, Altmann D (2013) Assaí—an energy view on an Amazon residue. Biomass Bioenergy 58:76–86

25. Da Silva RP (2018) Use of açaí stone in the production of bricks in the potteries of the city of Imperatriz-MA. PhD dissertation, Federal University of Tocantins, Palmas, TO

26. Reis O, Silva IT, Silva IMO et al (2002) Production of energy briquettes from açaí seeds. In: Meeting of energy in rural areas, vol 4, Campinas (Produção de briquetes energéticos a partir de caroços de açaí. In: Encontro de energia no meio rural) [online]. http://www.proceedings.scielo.br/scielo.php?script=sci_arttext&pid=MSC000000022002000000044&lng=en&nrm=iso

27. Reichert JM, Rodrigues MF, Bervald CMP, Brunetto G, Kato OR, Schumacher MV (2015) Fragmentation, fiber separation, decomposition, and nutrient release of secondary-forest biomass, mechanically chopped-and-mulched, and cassava production in the Amazon. Agr Ecosyst Environ 204:8–16

28. Campos T, Daga J, Rodrigues EE, Franzener G (2006) Starch wastewater treatment by means of stabilization ponds. Engen Agríc 26:235–242 (Tratamento de águas residuárias de fecularia por meio de lagoas de estabilização)

29. Colin X, Farinet JL, Rojas O, Alazard D (2007) Anaerobic treatment of cassava starch extraction wastewater using a horizontal flow filter with bamboo as support. Biores Technol 98(8):1602–1607

30. Kuczman O, Gomes SD, Torres DGB, Alcantara MS (2011) Specific biogas production from manipueira in a single-phase reactor. Eng Agríc 31:143–149 (Produção específica de biogás a partir de manipueira em reator defase única)

31. Lopes S, Pezoa-García NH, Amaya-farfan J (2008) Nutritional quality of cupuaçu and cocoa proteins. Ciência Tecnol Food 28(2):263–268 (Qualidade nutricional das proteínas de cupuaçu e de cacau)

32. Cerón X, Higuita JC, Cardona CA (2015) Analysis of a biorefinery based on Theobroma grandiflorum (copoazu) fruit. Biomass Convers Biorefin 5(2):183–194

33. Robak, Balcerek M (2018) Review of second-generation bioethanol production from residual biomass. Food Technol Biotechnol 56(2):174–187
34. OIR and AOA (2013) Bioprocess systems applied for the production of bio-ethanol from lignocellulosic biomass of cocoa pod husk (Theobroma cacao L.) and other agricultural residues: a review. Afr J Biotechnol 12(35):5375–5388
35. Tock Y, Lai CL, Lee KT, Tan KT, Bhatia S (2010) Banana biomass as potential renewable energy resource: a Malaysian case study. Renew Sustain Energy Rev 14(2):798–805
36. Alkarkhi FM, bin Ramli S, Yong YS, Easa AM (2011) Comparing physicochemical properties of banana pulp and peel flours prepared from green and ripe fruits. Food Chem 129(2):312–318
37. Folegatti IS, Matsuura FCAU (2004) Banana processing. Processamento de banana [Online]. https://www.agencia.cnptia.embrapa.br/recursos/Livro_Banana_Cap_13ID-PA3643xufd.pdf
38. Souza O, Schulz MA, Fischer GAA, Wagner TM, Sellin N, Esu R (2012) Alternative biomass energy: bioethanol from banana peel and pulp. Braz J Agric Environ Eng 16:915–921 (Energia alternativa de biomassa: bioetanol a partir da casca e da polpa de banana, Revista Brasileira Engen. Agríc. Ambient)
39. Gabhane J, Prince William SPM, Gadhe A, Rath R, Vaidya AN, Wate S (2014) Pretreatment of banana agricultural waste for bio-ethanol production: individual and interactive effects of acid and alkali pretreatments with autoclaving, microwave heating and ultrasonication. Waste Manag 34(2):498–503
40. Guerrero B, Aguado PL, Sánchez J, Curt MD (2016) GIS-based assessment of banana residual biomass potential for ethanol production and power generation: a case study. Waste Biomass Valoriz 7(2):405–415