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POSSIBILITIES FOR ENERGY USE OF AGRICULTURAL RESIDUE FROM COCOA PLANTATIONS

POSSIBILIDADES DE APROVEITAMENTO ENERGÉTICO DO RESÍDUO AGRÍCOLA DA LAVOURA CACAUEIRA[1]

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Abstract
The energetic use of agricultural residue may be an important alternative for the low-carbon economy. The cocoa crop generates a relevant amount of agricultural residue in the form of cocoa husk biomass. This study aims to identify the technological routes available for the energy use of

Resumo
O aproveitamento energético dos resíduos agrícolas é uma importante alternativa para a economia de baixo carbono. A lavoura cacaueira gera relevante quantidade de resíduo agrícola na forma de biomassa de casca de cacau. Este estudo identificou rotas tecnológicas disponíveis para o aproveitamento

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agrarian residue from the cocoa plantation and to quantify the capacity to supply cocoa husk biomass from cocoa plantation as a usable residue for energy purposes. Previous studies indicate that cocoa husk biomass has relevant qualities for conversion into energy products by various technological routes, such as pyrolysis, anaerobic digestion, and fermentation. The capacity to supply cocoa husk biomass as a usable by-product for energy purposes was found to be significant. The methodology adopted was bibliographic research, obtaining direct and indirect data from official agencies, in addition to research in scientific literature, using the deductive method. The results identified the environmental and economic benefits of using cocoa husk biomass as an energy source, with options for the commercialization of energy, bio-oil, biogas, bioethanol, biochar, briquettes, or pellets. Additionally, there are the possibilities of serving as animal feed, production of organic fertilizers, biofertilizers, and substrate for producing enzymes.

Keywords: agricultural residue; cocoa plantation; efficiency; low carbon economy.

energético desse resíduo e quantificou a capacidade de fornecimento aproveitável para fins energéticos. Estudos anteriores apontam que a biomassa de casca de cacau apresenta qualidades relevantes para a conversão em produtos energéticos por diversas rotas tecnológicas, como pirólise, biodigestão anaeróbia e fermentação. A capacidade de fornecimento desse subproduto aproveitável para fins energéticos encontrou volumes expressivos. A metodologia adotada foi de pesquisa bibliográfica, com a obtenção de dados diretos e indiretos oriundos de órgãos oficiais, além de pesquisa em literatura científica, por meio do método dedutivo. Os resultados identificaram os benefícios ambientais e econômicos da utilização da biomassa de casca de cacau como fonte energética, com opções para a comercialização de energia, bio-óleo, biogás, bioetanol, biocarvão, briquetes ou pellets e sua adequação às políticas estaduais de preservação da vegetação nativa. Somam-se, ainda, as possibilidades de servir para a alimentação animal, produção de fertilizantes orgânicos, biofertilizantes e substrato para a produção de enzimas.

Palavras-chave: *economia de baixo carbono; eficiência; lavoura cacaueira; resíduo agrícola.*

Introduction

The implementation of strategies based on natural solutions, aimed at fulfilling the international commitments of the country, presents itself as an opportunity to integrate agents and sectors. Such strategies provide biodiversity gains, enable the generation of energy from renewable sources, contribute to the rescue of culture and native biomes, in addition to increasing income possibilities, social benefits and facilitating improvements to the national energy matrix.

The residue from cocoa production in the *cabruca* model (agricultural cultivation harmoniously combined with the presence of native trees) has a high calorific value; its energy use, in association with the policy of the state of Bahia to recover the Atlantic Forest biome, can enable its sustainable expansion, while aggregating social, economic and environmental benefits.

This article aims to identify the technological routes available for the energy use of agricultural residue from cocoa crops and to quantify the supply capacity of cocoa husk biomass as a usable residue of cocoa crops for energy purposes.

This study has the potential to influence the adoption of similar practices in other cocoa-producing countries. The methodology used was based on bibliographic research, with the collection of direct and indirect data from official agencies, complemented by investigations in the scientific literature. The deductive method works as a central vector in the development of the work. The results identified the environmental and economic benefits of using agricultural residue from cocoa crops as an energy source.

The research is part of a growing trend focused on the energy use of waste, with emphasis on the valorization of agricultural waste as a strategic energy resource. Technical Note DEA 17/14, devised by the Ministry of Mines and Energy, shows that rural waste, when harnessed for energy use, is economically viable and can be competitive in specific energy markets, such as biomethane and electricity generated from biomass. The analysis details the logistical and operational costs, as well as the potential for energy generation and substitution of fossil sources, reinforcing alignment with the energy transition and the Sustainable Development Goals (SDGs). Additionally, it seeks to highlight that the harnessing waste for energy use via technologies such as pyrolysis and gasification can not only mitigate environmental impacts but also boost sustainable economic development by creating new markets for products derived from biomass.

In the cocoa farming context, this study is also aligned with contemporary analyses that aim to integrate economic, social, and environmental sustainability into agricultural production. The technical report prepared by CocoaAction Brasil, Instituto Arapyaú, and WRI Brasil shows that different cocoa production models—such as agroforestry systems (AFS) and the *cabruca* system—are economically viable and can be improved with sustainable practices, including the use of organic waste generated on properties. The relevance of this approach is even clearer when considering that most cocoa-producing establishments in the south of Bahia adopt agroforestry systems, with the potential to integrate waste management technologies such as anaerobic digestion. This synergy is also addressed by authors who reinforce the role of biogas as a vector of sustainability, by converting waste into energy and fertilizers, reducing greenhouse gas emissions and promoting environmental and economic gains, especially in rural contexts.

The methodology of this article was developed via exploratory research based on bibliographic and documentary analysis with indirect data collection from official agencies and public and private institutions. The investigation considered the scientific literature, technical production, sectoral reports, and legal and technical standards, all associated with biofuels and the low-carbon economy. The collected data were qualitatively and quantitatively analyzed, with the adoption of the deductive method as the central vector for conducting the work.

The approach adopted in this study dialogues not only with technical aspects of the energy conversion of agricultural waste but is also anchored in the epistemic theoretical contribution of the human sciences, which contributes to the critical understanding of the relationship between society, environment, and technology. In this sense, by considering sustainable production systems and local knowledge—such as cocoa cultivation in *cabruca* systems—this work incorporates a holistic and interdisciplinary vision that recognizes the role of culture, environmental policy, and socioeconomic justice in the transition to a low-carbon economy. The analysis of the literature consulted pointed out that the use of organic waste contributes not only to energy generation, but also to the implementation of SDGs, promoting positive impacts on rural communities and expanding access to clean and decentralized energy solutions.

Likewise, the data and reflections of the report prepared by CocoaAction Brasil, Instituto Arapyaú, and WRI Brasil reveal that the economic sustainability of cocoa production in Brazil is deeply linked to the valorization of traditional practices and integrated with environmental conservation, such as agroforestry systems. Such perspectives, coming from the human sciences, allow us to articulate technical knowledge with human and ecological values, understanding that the energy transition cannot be treated only as a matter of efficiency, but as a social, cultural, and ethical process. Thus, the energy use of biomass from cocoa crops, especially in contexts such as the Bahian cabruca, proves to be an alternative that reconciles technological innovation, environmental justice, and territorial resilience.

1 Harnessing biomass for energy use

The use of fossil fuels and the industrialization of agriculture, among other factors, have destabilized the environment (Rockström *et al.*, 2009). The human influence on planetary harmony is such that a new geological era called the Anthropocene is already being suggested, replacing the Holocene (Steffen *et al.*, 2015). Humanity is responsible for global warming, which is caused by the emission of greenhouse gases, among other important influences on the biosphere. There is an urgent need to promote energy transition to placate climate change (IPCC, 2021). In this context, humanity needs to review its consumption and production patterns.

Agricultural waste is a by-product of crop production activities in its various stages. In the case of cocoa crops, the main by-product is cocoa husk biomass. To Ferraz Junior *et al*. (2022), renewable energy are considered alternative sources to fossil fuels, and comprise naturally replenished sources, which includes those derived from biomass. Thus, the use of agricultural waste as an energy source contributes to a low-carbon economy, as do bioenergy and renewable energies. This alternative can mitigate pressures on natural resources and reduce the demand for fossil fuels. In addition to configuring a sustainable energy alternative, the use of agricultural waste can represent a gain in crop efficiency, with an increase in income or a decrease in energy-related costs.

Brazil already uses sugarcane bagasse, lye, rice husks, tallow, and animal fat, but there is still a large supply of residue from sugarcane (straws and tips, vinasse, and filter cake), woodchips, soybean and corn straws, coffee husks, coconut residues, beans, peanuts, cassava, cocoa, among others (Brasil, 2020).

2 Production data regarding cocoa crop and respective agricultural residue in Brazil and in the world

The 2020/2021 cocoa harvest was estimated to produce 875,000 tons in the Americas, 3,871,000 tons in Africa, and 278,000 tons in Asia and Oceania, which corresponds, respectively, to 17%, 77%, and 6% of the estimated world production for the period (Zugaib, 2021). In this context, only twelve countries concentrate almost all of the cocoa bean production in the world, five of which are in the American continent, namely, Brazil, Colombia, Ecuador, Peru, and the Dominican Republic; five countries on the African continent, namely Cameroon, Côte d'Ivoire, Ghana, Nigeria, and Uganda; and two countries on the Asian continent and Oceania, namely Indonesia and Papua New Guinea (Zugaib, 2021). Thus highlighting the importance of cocoa cultivation for the global southern hemisphere.

In 2020, cocoa production in Brazil occupied an area of 589,153 hectares intended for harvesting, adding up to a production of about 270 thousand tons (IBGE, 2021), as shown in Table 1.

Table 1. Area intended for harvesting, harvested area, quantity produced, average yield, and value of cocoa bean production, Brazil, 2011–2020.

Year	Area intended for harvesting (hectares)	Harvested area (hectares)	Quantity produced (tons)	Average yield of production (kg per hectare)	Production value (in thousands of reais)
2011	682,482	680,484	248,524	365	1,272,811
2012	686,541	684,333	253,211	370	1,234,157
2013	692,435	689,276	256,186	372	1,214,038
2014	707,106	704,122	273,793	389	1,589,535
2015	704,288	702,841	278,299	396	2,202,371
2016	732.585	720,055	213,871	297	2,007,189
2017	591,199	590,813	235,809	399	1,686,447
2018	577,550	577,191	239,318	415	2,167,200
2019	582,010	581,897	259,451	446	2,514,258
2020	589,153	588,501	269,731	458	3,223,892

Source: IBGE (2021).

Based on the data cataloged from 2011 to 2020, the estimated annual average of cocoa bean production in Brazil was 252,819 tons. An opportune fact, deserving of a very brief digression, is that, a variation was observed in the 2015/2016 and 2016/2017 harvests, which were severely impacted by the water crisis in Bahia (CEPLAC, 2016), an important Brazilian agricultural state (IBGE, 2021). Moreover, this water crisis was the main responsible for the drop in cocoa production in 2016, especially in Bahia, despite having reached all national agricultural regions (Brasil [...], 2017; A importação [...], 2017). According to Vieira (2016), the drought worsened in Bahia from 2015 onwards, affecting areas in the south and southwest of the state that historically did not suffer from such long and severe droughts. Rainfall in cities in the cocoa-growing region of Bahia decreased by 18% to 96% in 2015, compared to the average of the previous fifteen years, with a severe drop in water availability in water sources in 2016 (CEPLAC, 2016).

The production of one ton of cocoa beans results in the production of six (Santos; Silva, 2015 *apud* Correa *et al.*, 2016, p. 2) to eight tons (Coutinho, 2018; Mororó, 2012; Pereira, 2013; Silva, 2018) of fresh cocoa husks. Biomass obtained from cocoa husks is a promising source of fuel, similar to other agricultural residues also used in energy production (Correa *et al.*, 2016; Pereira, 2013; Pinheiro; Silva, 2016; Silva, 2018). Due to the high moisture content, cocoa shell biomass, must be transformed into chips before dry use, resulting in a dry mass equivalent to 20% of the fresh mass (Pereira, 2013).

These data suggest that, in the most conservative estimate (ratio of six tons of fresh cocoa husk biomass to one ton of cocoa beans), the cocoa crop produced, worldwide, 30,144,000 tons of fresh cocoa husk biomass in the 2020/2021 harvest, and in Brazil the cocoa crop produced, on average, 1,618,386 tons of fresh cocoa husk biomass per year in the last decade. Thus, the cocoa crop produces a large amount of cocoa husk biomass that can be used for energy purposes. It is an underused raw material that can be converted into various energy sources. Thus, the use of cocoa by-products can serve as an increase in income for cocoa growers, reduce the costs of the activity and establish more favorable relations with the environment by reducing the demand for other energy resources or the conversion of land use itself.

3 Fresh cocoa husk biomass as agricultural residue from cocoa plantations, which can be used for energy purposes

According to data from the IEA (2021), the traditional use of biomass corresponded, in 2020, to 4% of the energy supply in the world, a significant portion of this energy source. In this context, cocoa husk biomass can replace some of the traditional use of biomass. According to Odesola *et al.* (2010), the conversion of dry cocoa husk biomass into biochar has an efficiency of 79.9%. Thus, the agricultural residue from the cocoa crop could have produced 4,817,011 tons of biochar in the 2020/2021 cocoa harvest period in the world; and in Brazil, 258,618 tons of biochar would have been produced in 2020.

Its use for energy purposes can also reduce the demand for other sources of electricity. According to Pereira (2013), a cocoa plantation that produces about one ton per year can have a power of 0.76 kW, corresponding to the surplus energy in a system of cogeneration of energy for drying cocoa beans and generating electricity from the surplus in decentralized units.

The intersection in Tables 2 and 3 allowed for the estimation of data regarding the production of cocoa beans, fresh cocoa husk biomass, dry cocoa husk biomass, an equivalent power in a cogeneration system and potential for conversion into biochar in several geographic areas.

Table 2. Estimated production of cocoa beans, fresh cocoa shell biomass, dried cocoa shell biomass, equivalent power in a cogeneration system and possibility of conversion into biochar, continents, 2020/2021 harvest.

Origin	Cocoa beans (tons)	Fresh cocoa husk biomass (tons)*	Dried cocoa husk biomass (tons)**	Equivalent power in a cogeneration system (kW)***	Possibility of conversion to biochar (tons)****
Americas	875,000	5,250,000	1,050,000	798,000	838,950
Africa	3,871,000	23,226,000	4,645,200	3,530,352	3,711,515
Asia and Oceania	278,000	1,668,000	333,600	253,536	266,546

* Adopted a ratio of six tons of fresh cocoa husk to one ton of cocoa beans.
** The ratio of one ton of dried cocoa husks for every five tons of fresh cocoa husk is adopted.
***Adopted the ratio of 0.76kW for each ton of cocoa husk biomass dried in chips in a cogeneration system, with the ratio corresponding to the surplus.
****Adopted the ratio of 0.799 for each ton of dry cocoa husk biomass in chips.
Sources: Coutinho (2018); Odesola *et al.* (2010); Pereira (2013); Silva (2018); Santos and Silva (2015); Correa *et al.* (2016); and Zugaib (2021).

While the data in Table 2 refer to continental regions of the world, the data in Table 3 refer to the world and Brazil. In this way, it is possible to have a perception of the global reality and observe Brazilian circumstances.

Table 3. Estimated production of cocoa beans, fresh cocoa shell biomass, dried cocoa shell biomass, equivalent power in a cogeneration system and the possibility of conversion into biochar, Brazil, 2020, and world, 2020/2021 harvest.

Origin	Cocoa beans (tons)	Fresh cocoa husk biomass (tons)*	Dried cocoa husk biomass (tons)**	Equivalent power in a cogeneration system (kW)***	Possibility of conversion to biochar (tons)****
World	5,024,000	30,144,000	6,028,800	4,581,888	4,817,011
*Brazil*****	*269,731*	*1,618,386*	*323,677*	*245,994*	*258,618*

* Adopted a ratio of six tons of fresh cocoa husk to one ton of cocoa beans.
** Adopted the ratio of one ton of dried cocoa husks for every five tons of fresh cocoa husk.
***Adopted the ratio of 0.76kW for each ton of cocoa husk biomass dried in chips in a cogeneration system, with the ratio corresponding to the surplus.
****Adopted the ratio of 0.799 for each ton of dry cocoa husk biomass in chips.
The data from Brazil are a fraction already accounted for in the data from the world.
Sources: Coutinho (2018); IBGE (2021); Odesola *et al.* (2010); Pereira (2013); Silva (2018); Santos and Silva (2015); Correa *et al.* (2016).

Cocoa husk biomass has a characterization similar to that of other residues that are already transformed into fuels, with calorific value similar to that of sugarcane bagasse and eucalyptus, ranging from 15.89 to 19.04 MJ/kg in literature values, despite the high ash content that deserves attention in thermochemical processes (Coutinho, 2018; Pereira, 2013; Santos, 2016). Cocoa husk biomass is, therefore, an important alternative for energy use (Santos, 2016), being, for example: (i) for Coutinho (2018), the promising option of pyrolysis for the production of bio-oil; (ii) for Batista (2014) and Mororó (2012), anaerobic digestion is advantageous for the production of biogas, due to the high organic biodegradability; and (iii) for Pinheiro and Silva (2016) and Silva (2018), fermentation for the production of bioethanol is promising, given the favorable obtention of fermentable sugars.

Cocoa husk biomass also has the versatility to be used in other sources of energy production via thermochemical processes of direct combustion, gasification, or pyrolysis and biological processes of anaerobic digestion or hydrolysis of lignocellulose (Pereira, 2013; Santos, 2016). According to Mororó (2012), one ton of fresh cocoa husk produces about 45 m^3 of biogas, with an approximate methane concentration of 53%, a production equivalent to 20 kg of liquefied petroleum gas (Table 4). The purification or upgrading of biogas also enables the production of biomethane by the process of removing carbon dioxide and other gases, raising the concentration of methane to values between 80% and 99% (Ferraz Junior *et al.*, 2022; IEA, 2021).

Table 4. Estimated production of cocoa beans, fresh cocoa shell biomass, dried cocoa shell biomass, biogas and equivalence in liquefied petroleum gas, Brazil, 2020, and world, 2020/2021 harvest.

Origin	Cocoa beans (tons)	Fresh cocoa husk biomass (tons)*	Estimated equivalence in biogas (m^3)**	Estimated equivalence in biomethane (m^3)***	Estimated equivalence in liquefied petroleum gas (kg)****
World	5,024,000	30,144,000	1,356,480,000	718,934,400	602,880,000
*Brazil*****	*269,731*	*1,618,386*	*72,827,370*	*38,598,506*	*32,367,720*

* Adopted a ratio of six tons of fresh cocoa husk to one ton of cocoa beans.
** Adopted the ratio of 45 m^3 of biogas for each ton of fresh cocoa husk biomass.
***Adopted the ratio of 45 m^3 of biogas for each ton of fresh cocoa husk biomass.
****It is estimated that 47% of the total volume will be removed, which corresponds to what would represent the proportion of gases other than methane.
The data from Brazil are a fraction already accounted for in the data from the world.
Sources: Coutinho (2018); IBGE (2021); Odesola *et al.* (2010); Pereira (2013); Silva (2018); Santos and Silva (2015); and Correa *et al.* (2016).

Notably, the energy use of cocoa biomass can, by itself, present a series of environmental and economic benefits since there is more than one possible technological route. However, such use can still be developed in line with state policies for the preservation of native vegetation, as a way of promoting and enabling production using agroforestry systems such as *cabruca*.

4 Energy use of agricultural residues from cocoa production as a possibility to facilitate state policies for the preservation of native vegetation

The Convention on Biological Diversity (CBD), signed during the UN Conference on Environment and Development (ECO-92), held in Rio de Janeiro, in 1992, and incorporated into the Brazilian legal system via executive order No. 2,519, of March 16, 1998, is recognized as the consecration of a new holistic, systemic or integral paradigm for the protection of biodiversity, since it seeks to safeguard biodiversity on a global scale, understanding the interdependence between the essential ecological processes that govern life in all its forms (Sarlet; Fensterseifer, 2022).

In this sense, the Constitution of the Federative Republic of Brazil of 1988 already provides, in its Art. 225, Paragraph 4, the essential function of forest biomes for the preservation of biodiversity (Brazil, [2022]):

> Art. 225. Everyone has the right to an ecologically balanced environment, which is an asset of common use and essential to a healthy quality of life, and both government and community shall have the duty to defend and preserve it for present and future generations. […]
> […]
> Paragraph 4. The Brazilian Amazonian Forest, the Atlantic Forest, the Serra do Mar, the Pantanal Mato-Grossense and the coastal zone are part of the national patrimony, and they shall be used, as provided by law, under conditions which ensure the preservation of the environment, therein included the use of mineral resources. […]

In the same vein, Federal Law No. 11,428, of December 22, 2006, which defines the use and protection of native vegetation of the Atlantic Forest biome, provides, in its Art. 6, that the protection and use of the Atlantic Forest biome have as a general objective the sustainable development and, for specific objectives, the safeguarding of biodiversity; human health; landscape, aesthetic, and touristic values; the water regime; and social stability (Brasil, 2006).

Art. 7, item III, however, delimits that the protection of the use of the Atlantic Forest biome will be carried out under conditions that ensure, among others, the promotion of public and private activities compatible with the maintenance of ecological balance (Brasil, 2006).

The cocoa-producing region in the south of Bahia presents a typical form of farming that has led to the perpetuation of remnants of the Atlantic Forest, even in anthropized areas (Lobão, 2007; Lobão *et al*. 2012), and the conservation of native tree species within the plantations (Sambuichi, 2009a). It is the *cabruca*, an agroforestry system installed in the subforest, responsible for maintaining ecological corridors and safeguarding endemic species.

The *cabruca* agroforestry system was regulated and defined by the state executive order No. 15,180, of June 2, 2014, on the management of forests and other forms of vegetation, given its strategic relevance for the conservation of the Atlantic Forest biome in the state of Bahia, and it is up to the public authorities to promote the activity.

Art. 17, item III, of the aforementioned legislation defines that the conservation of traditional cocoa cultivation areas in the *cabruca* agroecosystem aims to promote a sustainable management of the agrobiodiversity present in the *cabruca* system, with the objective of ensuring its economic sustainability and improving the profitability of the rural producer (Bahia, 2014).

Essentially, the *cabruca* system is an agroforestry system (AFS). Among other possible definitions, it is a form of agricultural cultivation harmoniously integrated with the presence of trees. This model contributes to mitigating the impacts of forest fragmentation and edge effects, even serving as an ecological corridor (Sambuichi, 2009b). For these reasons, the agroforestry system has the capacity to assist in the conservation of biodiversity (Sambuichi, 2009b; Seehusen; Wedge; Oliveira Júnior, 2011).

The Paris Agreement is considered a milestone in the global fight against the climate crisis, with land use and occupation being factors that significantly influence total greenhouse gas emissions and represent the main source of emissions in Brazil. Based on this perspective, via Ordinance n. 22,387, of February 25, 2021, the *Programa Harpia de Gestão da Vegetação Nativa* (Harpy Eagle Program for Native Vegetation Management) was instituted in the state of Bahia by the Institute of Environment and Water Resources (INEMA, 2021).

Among the objectives of the program, the items II and IV of Art. 1 are highlighted, which are as follows (INEMA, 2021):

> II–to propose guidelines for the restoration of native vegetation in the state;
> IV–to propose goals for the reduction of deforestation and for the increase of areas under restoration in the state;
> […] (free translation)[2].

Finding mechanisms that enable the promotion and maintenance of production in the *cabruca* system adds benefits in several areas, with ample support in national and state legislation. In a recent study on the topic of economic viability of production systems with *cabruca* cocoa carried out by the Cocoa Farming Research Center (CEPLAC, 2021), it was identified that *cabruca* without adequate shade management does not present good economic results.

However, the study points out that

> […] this production model, when well-managed, presents an excellent opportunity for the sector in terms of environmentally differentiated agricultural production. Treating *cabruca* as an opportunity from a historical and environmental perspective can transform the current scenario from a negative spiral, in which these producers have remained in recent years, into a positive spiral (CEPLAC, 2021, p. 38, free translation)[3].

2 In the original: "II – propor orientações para a restauração da vegetação nativa no estado; IV – propor metas para a redução do desmatamento e para o aumento das áreas em restauração no estado".

3 In the original: "[…] esse modelo de produção, quando bem manejado, apresenta excelente oportunidade para o setor no que tange a uma produção agrícola ambientalmente diferenciada. Tratar a cabruca com um olhar de oportunidade através de um cunho histórico e ambiental pode transformar o cenário atual de espiral negativa em que esses produtores têm se mantido nos últimos anos em uma espiral positive".

To this end, in addition to direct and/or indirect incentive mechanisms, such as payment for environmental services, already provided for in the aforementioned state executive order on the management of forests and other forms of vegetation, and the carbon market (Gama-Rodrigues *et al.*, 2021), the use of cocoa crop residues for energy generation, especially from *cabruca*, is a possibility in line with policies for the preservation of native forest in the state of Bahia.

According to the *Plano Nacional de Energia 2050* (National Energy Plan 2050), published by the Energy Research Company (Brasil, 2020), decarbonization strategies usually focus its efforts on objectives that best suit the local context, considering aspects that add benefits in the following dimensions: energy (non-emitting sources with greater efficiency), environmental (use of resources and legal adequacy), economic (alignment with the economic priorities outlined), and technological (aligned with industrial development and technological).

Fostering integrated systems for the preservation of biodiversity and energy use with low environmental impacts contributes to the fulfillment of the international commitments of the country, presents benefits for energy and food security and introduces possibilities to make it economically feasible for regional producers to maintain activities integrated with the forest.

Conclusion

Cocoa husk biomass is a waste product from cocoa crops that can be used for energy purposes. Its use is promising and is in line with the decarbonization goals associated with socio-environmental responsibility. The adoption of practices for the energy use of agricultural waste can occur in several cocoa-producing countries around the world. This study can also serve as a stimulus to research on the energy use of agricultural a wide range of residues, from other crops to cocoa husks.

Cocoa husk biomass can increase income via the commercialization of electricity, bio-oil, biogas, biomethane, bioethanol, biochar, briquettes, or pellets. In addition, there are the possibilities of cocoa husk biomass being used for animal feed and the production of organic fertilizers (Mororó, 2012; Pereira, 2013; Coutinho, 2018), substrate for the production of enzymes (Batista, 2014), composting, and cellulose (Mororó, 2012).

Considering the average yield of cocoa bean production in Brazil (IBGE, 2021), there is significant room for increasing production based on the genetic improvement of the cocoa tree (Ahnert *et al.*, 2018; Mororó, 2012), with the consequent increase in the supply of agricultural waste that can be used for energy purposes, without increasing the planted area. Thus, the increase in cocoa production can be accompanied by a greater supply of energy resources that are favorable to the environment and the low-carbon economy. The production of food and energy from the same crop promotes sustainable development and avoids competition between food and energy production, while also contributing to food and energy security.

Moreover, the production of energy using agricultural residues from cocoa crops in agroforestry systems such as *cabruca* has great potential for compliance with state policies for the preservation of native vegetation, in addition to meeting the commitments made by the country with regard to the reduction of greenhouse gas emissions.

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