



SUSTAINABILITY ANALYSIS IN MUNICIPALITIES PRODUCING AÇAÍ (*Euterpe oleracea* Mart) IN THE NORTHERN REGION OF BRAZIL

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ABSTRACT

Objective: The objective of this study is to investigate the sustainability analysis in municipalities producing açai (*Euterpe oleracea* Mart.) in the northern region of Brazil, to evaluate sustainability in ten towns with the most significant production of açai in the state of Pará, Brazil, the largest producer of açai in the country.

Theoretical Framework: The production of açai (*Euterpe oleracea* Mart.) in the Amazon has been changing its cultivation model, moving from family farming to intensive extractivism, resulting in socio-environmental and economic scenarios transformations.

Method: Data were collected from the Brazilian Institute of Geography and Statistics (IBGE) database, and the Dashboard of Sustainability (DS) index was applied to assess the level of sustainability. The index was composed of 31 indicators divided into social (n=14), environmental (n=12) and economic (n=5) dimensions.

Results and Discussion: The results showed variations in the three dimensions, with more unfavorable results regarding achieving a high level of sustainability. For all municipalities, the Sustainability Index ranged from 20 to 60, generally classifying the condition as Average or Poor. The worst score on the index was for the city of Igarapé-Miri, while the best score was for Barcarena.

Research Implications: The diagnosis of the central açai-producing municipalities can contribute to public management in improving the performance of sustainability indicators to face the socio-environmental and economic challenges of the region.

Originality/Value: This study contributes to the literature by providing results in the three dimensions of sustainability, environmental, social, and economic, about açai production and its impacts in the Amazon region.

Keywords: Amazon, Dashboard of Sustainability, Non-Timber Product, Socio-Environmental and Economic Impacts of Açai Production, Sustainability Indicators.

ANÁLISE DE SUSTENTABILIDADE EM MUNICÍPIOS PRODUTORES DE AÇAÍ (*Euterpe oleracea* Mart) NA REGIÃO NORTE DO BRASIL

RESUMO

Objetivo: O objetivo deste estudo é investigar a Análise de sustentabilidade em municípios produtores de açai *Euterpe oleracea* Mart. na região norte do Brasil com o intuito de avaliar a sustentabilidade em dez municípios com maior produção de açai no estado do Pará, Brasil, maior produtor de açai do país.

Referencial Teórico: A produção de açai (*Euterpe oleracea* Mart.) na Amazônia vem mudando o modelo de cultivo, passando do familiar para o extrativismo intensivo, resultando em transformações nos cenários socioambientais e econômicos.

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Método: Foram coletados dados do banco de dados do Instituto Brasileiro de Geografia e Estatística (IBGE), e aplicado o índice Dashboard of sustainability (DS) para avaliar o nível de sustentabilidade. O índice foi composto por 31 indicadores divididos em dimensões social (n=14), ambiental (n=12) e econômica (n=5).

Resultados e Discussão: Os resultados mostraram variações nas três dimensões, com resultados mais desfavoráveis sobre o alcance de alto nível de sustentabilidade. Para todos os municípios, o índice de Sustentabilidade variou de 20 a 60, classificando, de forma geral, a condição como *Média* ou *Ruim*. A pior pontuação no índice foi para o município de Igarapé-Miri, enquanto a melhor pontuação foi para Barcarena.

Implicações da Pesquisa: O diagnóstico dos principais municípios produtores de açaí pode contribuir com a gestão pública na melhoria do desempenho dos indicadores de sustentabilidade para enfrentar os desafios socioambientais e econômicos da região

Originalidade/Valor: Este estudo contribui para a literatura ao fornecer resultados nas três dimensões da sustentabilidade: ambiental, social e econômico em relação à produção do açaí e seus impactos na região amazônica.

Palavras-chave: Amazônia, Dashboard of Sustainability, Produto Não Madeireiro, Impactos Socioambientais e Econômicos da Produção de Açaí, Indicadores de Sustentabilidade.

ANÁLISIS DE SOSTENIBILIDAD EN MUNICIPIOS PRODUCTORES DE AÇAÍ (*Euterpe oleracea* Mart) EN LA REGIÓN NORTE DE BRASIL

RESUMEN

Objetivo: El objetivo de este estudio es investigar el Análisis de Sostenibilidad en municipios productores de açaí *Euterpe oleracea* Mart. en la región norte de Brasil con el objetivo de evaluar la sostenibilidad en diez municipios con mayor producción de açaí en el estado de Pará, Brasil, el mayor productor de açaí del país.

Marco Teórico: La producción de açaí (*Euterpe oleracea* Mart.) en la Amazonía viene cambiando el modelo de cultivo, pasando de la agricultura familiar al extractivismo intensivo, resultando en transformaciones en el escenario socioambiental y económico.

Método: Los datos se recopilaron de la base de datos del Instituto Brasileño de Geografía y Estadística (IBGE) y se aplicó el índice Dashboard de sostenibilidad (DS) para evaluar el nivel de sostenibilidad. El índice estuvo compuesto por 31 indicadores divididos en dimensiones sociales (n=14), ambientales (n=12) y económicas (n=5).

Resultados y Discusión: Los resultados mostraron variaciones en las tres dimensiones, con resultados más desfavorables respecto al logro de un alto nivel de sostenibilidad. Para todos los municipios, el índice de Sostenibilidad osciló entre 20 y 60, clasificando generalmente la condición como Regular o Mala. La peor puntuación en el índice fue para el municipio de Igarapé-Miri, mientras que la mejor puntuación fue para Barcarena.

Implicaciones de la investigación: El diagnóstico de los principales municipios productores de açaí puede contribuir a la gestión pública en la mejora del desempeño de los indicadores de sostenibilidad para enfrentar los desafíos socioambientales y económicos de la región.

Originalidad/Valor: Este estudio contribuye a la literatura al proporcionar resultados en las tres dimensiones de la sostenibilidad: ambiental, social y económica en relación con la producción de açaí y sus impactos en la región amazónica.

Palabras clave: Amazonía, Panel de Sostenibilidad, Producto No Maderable, Impactos Socioambientales y Económicos de la Producción de Açaí, Indicadores de Sostenibilidad.

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1 INTRODUCTION

As human populations continue to grow, especially in tropical countries (Bar-On *et al.*, 2018), the pressure on tropical forest lands and their resources is expected to increase, potentially hindering the attainment of the Global Sustainable Development Goals (Barros *et al.*, 2024), highlighting the current environmental crisis (Mirón *et al.*, 2023). As a result, many regions have experienced more significant pressure from widespread environmental exploitation (Selvaraj *et al.*, 2021), including the Amazon region, which is home to one of the Brazilian biomes with the highest rates of loss of forest areas (Mapbiomas, 2023).

The Amazon biome presents a great diversity of non-timber forest products (NTFPs) as fibers, seeds, oils, resins, dyes, medicines, and various foods such as fruits and nuts, among others (Araujo *et al.*, 2024). Among the Amazonia NTFPs, the açai palm (*Euterpe oleracea* Mart.) has gained economic prominence due to its high fruit yield and other valuable plant products (Ximenes *et al.*, 2020; Ramos *et al.*, 2019). Native to the Amazon region, this palm belongs to the Arecaceae family (Oliveira *et al.*, 2020).

E. oleracea is a species that can reach up to 30 meters in height and occurs in hydromorphic soils, characteristic of floodplains, with a periodic tidal flooding regime divided between high tide and low tide, daily variations that promote the natural maintenance of humidity in floodplain areas (Rodrigues *et al.*, 2021, Felix *et al.*, 2021). During its flowering period, açai corresponds to 51% of the food supply for various pollinators (EMBRAPA, 2021a), with emphasis on native bees, which are essential pollinators for açai (Campbell *et al.*, 2018).

The açai fruit is the main product of the species and is primarily used to produce açai pulp, and it is considered a nutraceutical food, rich in proteins, fibers, lipids, vitamin E, and minerals (Araujo *et al.*, 2024). It also contains high levels of anthocyanins, pigments that promote health, improve blood circulation, and provide protection against arteriosclerosis (Silvestre *et al.*, 2016). In the Amazon region, particularly in the eastern part, the açai palm fruit has been traditionally consumed by local populations as a source of food (Brondízio, 2008).

Until the early 1990s, açai production was carried out to meet local communities' subsistence consumption (Tagore, 2017). However, from the 1990s onwards, açai consumption grew strongly in the national and international markets (Brondízio, 2008; Paz *et al.*, 2018; Veloz, 2020), which led to changes in the extraction/production models, ranging from family extraction to intensive management (Paz *et al.*, 2018). The demand for fruit pulp continues to grow, leading to increased production through a significant rise in açai palm density in natural stands managed by traditional populations, especially in the Amazon estuarine forest, which is



the core area for both açai consumption and production (IBGE, 2021). Among the Brazilian states, the state of Pará is the largest producer of açai, reaching the mark of 1,595,455 tons of açai per year (Tagore; Canto; Sobrinho, 2018; IBGE, 2022).

To meet the demand, the palm density in the forest is often subject to frequent, artificially selective thinning of undesirable plant species, ranging from large shrubs to emergent trees, reducing competition for space and light (Anderson, 1988; Oliveira *et al.*, 2007; Coradin *et al.*, 2022; Barros *et al.*, 2014). Intensification can boost natural açai density many times over (from 20 to more than 1,000 clumps per hectare; Freitas *et al.*, 2015) and even result in the complete replacement of the forest with açai monocultures, particularly near households (Anderson, 1988; Barros *et al.*, 2014). However, this can have positive and negative impacts (Campbell *et al.*, 2018; Trégido *et al.*, 2020), which can cause society to feel differently (Tagore, 2017).

For instance, the expansion and intensification of açai cultivation in the floodplain forests of the Amazonian estuary have led to changes in floristic composition, biodiversity loss, and ecological disruptions, jeopardizing the livelihoods of riverine communities (Hiraoka, 1993; Campbell *et al.*, 2018; Carvalho *et al.*, 2021). On the other hand, the intensification of açai cultivation can lead to other socio-environmental and economic benefits, especially in terms of increased income, employment, and the generation of social inclusion for producing municipalities, such as access to the acquisition of goods, greater visibility of women's participation, more significant financial support for small producers and improved housing (Trégido *et al.*, 2020; Tagore, 2017). In addition, the extractive exploitation can promote the maintenance of the standing forest, which increases the security of financial return for several actors in the process of the production chain of this fruit, factors that reflect the influence of the practice of açai production as an extractive bioeconomy (Tagore, 2017; Veloz, 2020; EMBRAPA, 2021).

For sustainability goals to be achieved, the environmental, social, and economic dimensions necessarily need to be in balance, especially in regions with ecological vulnerability (Krishna *et al.*, 2020), as is the case of forests in floodplain areas (Trégido *et al.*, 2020). In this sense, evaluating sustainability indicators is essential for identifying gaps in production chains that must be addressed in the search for more sustainable standards (Krishna *et al.*, 2020). Assessing sustainability performance and making sustainable decisions are crucial for advancing sustainable development, while addressing economic, environmental, and social dimensions (Noveiri *et al.*, 2024).



This study analyzed the sustainability of açai production in ten municipalities in Pará with the highest productivity of this fruit, applying the Dashboard of Sustainability (DS) Index using sustainability indicators in the environmental, social, and economic dimensions. The results obtained have the potential to help identify aspects and benefits of intensifying açai production in the municipalities that can be improved to make this production chain more sustainable, indicating, for example, which indicators can be improved. In this way, the results can serve as an auxiliary tool for public decision-making and contribute to developing programs to enhance indicators to help comply with sustainability principles.

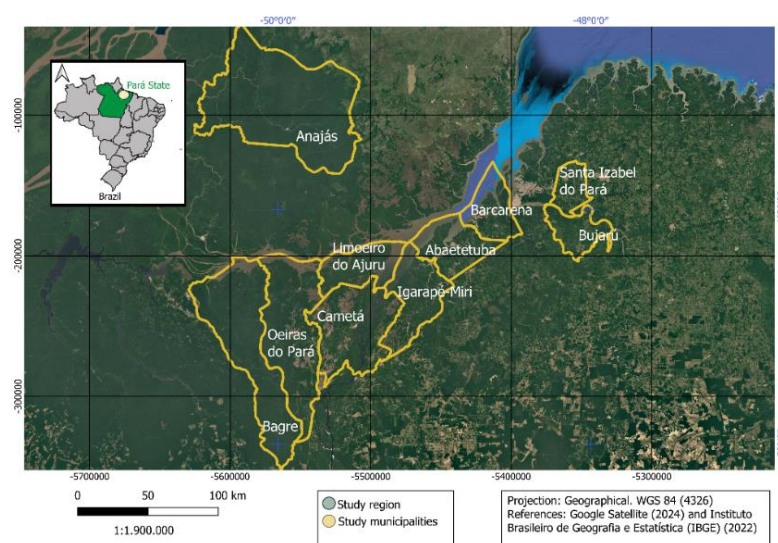
2 METHODS

2.1 STUDY AREA

Ten municipalities in the state of Pará were evaluated, with the highest production of açai in the state: Abaetetuba, Anajás, Barcarena, Bujarú, Bagre, Cametá, Igarapé-Mirim, Limoeiro do Ajurú, Oeiras do Pará and Santa Izabel do Pará (Figure1). Pará is located in the North region of Brazil (Figure 1) and has a territorial extension of 1,245,870,704 km², housing 144 municipalities and 8,116,132 inhabitants (IBGE, 2022). The region of the municipalities evaluated comprises floodplain areas characterized by flat and alluvial lands, which are exposed to both seasonal and tide-driven floodings (Silva & Jardim, 2016).

Figure 1

Location of municipalities evaluated in this study



Source: author, 2023.



2.2 DATA COLLECTION AND DASHBOARD OF SUSTAINABILITY CALCULATION

To assess the sustainability level of the municipalities producing açai, sustainability indicators were used. Subsequently, a sustainability index, the Dashboard of Sustainability, was applied, combining various social, economic, and environmental indicators. The process of selecting the indicators was based on the scientific literature, considering previous studies that have applied assessments based on indicators to measure the sustainability of other crops and products such as cocoa (*Theobroma cacao*) (Sulvarán *et al.*, 2014), palm oil (*Elaeis guineensis*) (Monteiro, 2013), beef production (Freitas *et al.*, 2019), biomass for bioenergy production (Flores *et al.*, 2018), and energy production (Naganathan & Chong; 2017; Garcia-Alvarez *et al.*, 2016; Santos, 2019). Recognizing indicators that can simplify reality and explain in values the indicators of different conditions is an analysis that seeks to aggregate dimensions, considering factors such as income, production, and population, among others, that reveal a relationship of belonging to the analyzed field (Mariosa *et al.*, 2019).

The first stage of the study consisted of data collection, which was carried out in November 2023. The data used in this study were obtained from the database of Brazilian Institute of Geography and Statistics (IBGE, <https://www.ibge.gov.br/>) and were used to determine sustainability indicators, considering information from the social, environmental, and economic spheres of each municipality. The data obtained from IBGE are related and comprise the information available up to 2022. After data collection, a set of 30 indicators was determined, which were 14 social, 12 environmental, and five economic (Table 1).

Some indicators have a positive expectation of sustainability, in which an increase in the indicator value reflects a benefit, as in the case of *number of producers with secondary education* and *revenue from açai production* (Table 1). On the other hand, indicators can also have a negative expectation, in which an increase in the indicator value generates a loss for sustainability, as is the case with the indicators *infant mortality* and *establishments using pesticides* (Table 1).

The data obtained for each indicator were normalized since the data for the indicators used had different units of measurement, for example, number of inhabitants (hab), kilogram/ton (kg/t), and percentage (%) (Table 1). Based on scientific literature (Scipioni *et al.*, 2009; Sulvarán *et al.*, 2014; Turra *et al.*, 2027; Silva, 2019; Freitas *et al.*, 2019; Yildirim *et al.*, 2022), the following equation was applied:



$$i = 100 \frac{(X - \text{worst})}{(\text{best} - \text{worst})}$$

i = municipal indicator assessed

X = obtained value of the municipal indicator

Best: best value of the indicator observed among the municipalities. If the indicator generates benefits for sustainability, the highest value observed for this indicator was used in the calculation. However, if the indicator generates harm to sustainability, the lowest value of this indicator is used.

Worst = worst value of the indicator observed among the municipalities. If the indicator generates benefits for sustainability, the lowest value observed for this indicator is used in the calculation. If the indicator generates harm to sustainability, the highest value of this indicator was used.

Table 1

Sustainability indicators assessed by dimension

Dimension	Unit	Source	Expectation
Social			
Population	n° of inhabitants	IBGE	-
HDI	rate	IBGE	+
Infant mortality	%	IBGE	-
Population density	inhabitants/km ²	IBGE	-
Female producers	n° of inhabitants	IBGE	+
Male producers	n° of inhabitants	IBGE	-
Households in urban areas	n° houses	IBGE	-
Households in rural areas	n° houses	IBGE	-
Farmers aged 25 years	n° of inhabitants	IBGE	-
Farmers aged 25 to 35	n° of inhabitants	IBGE	+
Farmers aged 35 to 45	n° of inhabitants	IBGE	+
Illiterate producers	n° of inhabitants	IBGE	-
Producers with high school education	n° of inhabitants	IBGE	+
Producers with higher education	n° of inhabitants	IBGE	+
Environmental			
Açai production 50 feet and more	ton	IBGE	-
Açai Production Area 50 feet and more	hectares	IBGE	-
Total area harvested of açai	hectares	IBGE	-
Use of pesticides	n° of properties	IBGE	-
Non-use of pesticides	n° of properties	IBGE	+
Receive technical assistance	n° of properties	IBGE	+
Does not receive technical assistance	n° of properties	IBGE	-
Producer using fertilizer	n° of properties	IBGE	-
Producers who do not use fertilizer	n° of properties	IBGE	+
Permanent crops	hectares	IBGE	+
Temporary crops	hectares	IBGE	+
Açai waste	Kg/ton produced	IBGE	-
Economic			



GDP	R\$	IBGE	+
Industry	R\$	IBGE	+
Revenue for açai production	R\$	IBGE	+
With financing for agricultural production	n° of properties	IBGE	+
No financing for agricultural production	n° of properties	IBGE	-

*HDI: Human Development Index: GDP: Gross domestic product
Source: author, adapted, (IBGE), 2023.

After standardization, the Dashboard of Sustainability index (Table 2) was applied, which measures the level of variation in sustainability and ranges from a classification considered *excellent* to *critical* thus demonstrating the relationship of the index with the level of sustainability. The Dashboard of Sustainability index brings together indicators from different spheres of sustainability to build a panel with measures assessing the social, economic, and environmental dimensions. It is considered an easy and straightforward communication tool with the general public (Scipioni, 2009).

Table 2

Dashboard of Sustainability Scores Ranking

Critical condition	Severe attention	Very bad	Bad	Average	Reasonable	Good	Very good	Excellent
0-11	12 - 22	23 - 33	34 - 44	45 - 55	56 - 66	67 - 77	78 - 88	89 - 100

Source: adapted from Turra; Melo; Silva (2017) and Santos (2019).

The following equations were used to calculate the index of each dimension:

Calculation of the social dimension

$$\text{Social dimension index} = \frac{(S \text{ indicator } 1 + S \text{ indicator } 2 + S \text{ indicator } 3 \dots)}{N_{\text{Social}}}$$

S indicator: the observed value of the social indicator

N Social: number of social indicators used

Calculation of the environmental dimension index

Environmental dimension index

$$= \frac{(Env \text{ indicator } 1 + E \text{ indicator } 2 + E \text{ indicator } 3 \dots)}{N_{\text{Environmental}}}$$



Env. indicator: the observed value of the environmental indicator

N Environmental: number of environmental indicators used

Calculation of economic dimension

Economic dimension index

$$= \frac{(Econ\ indicator\ 1 + Econ\ indicator\ 2 + Econ\ indicator\ 3 \dots)}{NEconomic}$$

Econ. indicator: the observed value of the social indicator

N Economic: number of economic indicators used

The overall Dashboard of Sustainability (DS) index was obtained by determining the average of the three dimensions (environmental, social, and economic) and dividing by three, following the equation:

$$DS = \frac{\text{Environmental dimension} + \text{Social dimension index} + \text{Economic dimension index}}{3}$$

After calculating the indicators and the sustainability index, the data from the municipalities were tabulated and evaluated. The average values of the social, environmental, and economic indicators were estimated to analyze the relationship of the municipalities in each dimension. The ggplot2 package (Wickham, 2016) was used to prepare the graphs and represent the results using R software (R Development Core Team, 2019; R Studio Team, 2020).

3 RESULTS AND DISCUSSION

None of the açai producing municipalities in Pará state evaluated in this study obtained high scores to achieve sustainability. It was possible to observe that the concept *Bad* was evident in all dimensions, with emphasis on the economic dimension that presented the idea considered *Very Bad* and *Severe* in most municipalities (Table 3). The best classification concept obtained was *Good* which was noticed only for one municipality regarding the environmental index (Table 3). These low scores suggest that in these açai-producing municipalities, there is a risk to sustainable production and conservation of the biome, signaling that ecosystem services provided by the Amazon rainforest, such as climate regulation and soil quality for cultivation,



may be compromised and threatening not only the maintenance of the ecological integrity of the biome but also populations that depend on production chains, mainly for food, as is the case with açai (Silva *et al.*, 2023; Freitas *et al.*, 2021; Tagore *et al.*, 2018).

Table 3

Classification of municipalities in the three dimensions of sustainability

Municipalities	Social Index	Concept	Environmental Index	Concept	Economic Index	Concept
Abaetetuba	41.14	Bad	49.92	Average	31.8	Very bad
Anajás	47.71	Average	74	Good	20.4	Severe
Barcarena	44.85	Average	41.33	Bad	56.6	Reasonable
Bujarú	41.14	Bad	59.16	Reasonable	27	Very bad
Bagre	53	Average	58.5	Reasonable	19.6	Severe
Cametá	51.28	Average	60.33	Reasonable	25.8	Very bad
Igarapé Miri	46.35	Average	33.66	Bad	38.4	Bad
Limoeiro do Ajurú	56.85	Reasonable	52	Average	21.6	Severe
Santa Izabel do Pará	52.85	Average	52.91	Average	25.4	Very bad
Oeiras do Pará	51.85	Average	62.41	Reasonable	19.8	Severe

Source: author, 2023.

In this way, sustainable production represents the maintenance of the integrity of the environment in the region, thus guaranteeing the production of açai, which consequently maintains the economic flow, generating social inclusion, reducing poverty, and environmental conservation. Therefore, there is a need to improve several aspects to achieve sustainable production in the açai production chain.

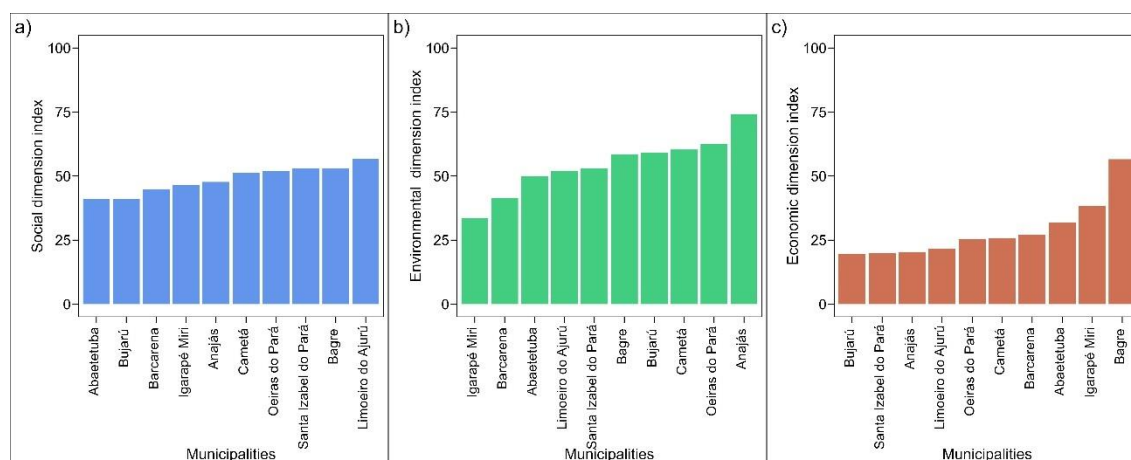
3.1 SOCIAL DIMENSION

Of the ten municipalities evaluated in this dimension (Fig. 2a), two presented *Poor* performance, seven municipalities with *Average* performance, and only one municipality with *Reasonable* performance. The best value observed was for the city of Limoeiro do Ajurú (Figure 2a, Table 3), with a score of 56.85, and the worst values observed were for the municipalities of Abaetetuba and Bujarú, which both presented a score of 41.14. The *Female producers* indicator presented unfavorable results for all municipalities evaluated; less than half of the workers in açai production are women (Table 1).



Figure 2

Results on the dimension of sustainability by municipality: a) Social, b) Environmental, and c) Economic dimension.



Source: author, 2023.

The invisibility of women in the açai production chain is still a reality in the region, even though they have a decisive participation in the production process (Rodrigues *et al.*, 2021). The result observed in this study is a reality that has already been reported in science previously. A survey conducted by Batista (2013) showed that the majority of men participating in the management of açai producing agrosystems in Cametá, Pará, at around 96.15%.

The inclusion of women in the agricultural production system is still a challenging process. Still, in açai production, this reality is gradually changing, as in some cases, they are at the forefront of the entire production process, from harvesting to marketing, generating income as the primary source, in which women are the family breadwinners (Rodrigues *et al.*, 2021). Cametá, Abaetetuba, and Igarapé Miri were the municipalities with the highest indicator values of female producers (Table 1). Although the inclusive reality is already occurring, this study highlighted two conditions: social inclusion, as one of the aspects of sustainability, happening gradually, and social justice, a condition not yet achieved by women in the process of equality within the açai production chain (Dempsey *et al.*, 2011). Still, on social aspects, a study carried out on social transformations in the floodplain areas of the municipality of Abaetetuba highlighted the transformations in the residences of riverside dwellers, previously in rustic patterns of wooden constructions and currently in masonry (Tagore, 2017). This spatial transformation in the residences is attributed to the power of acquisition of goods as one of the results of açai production.

The relationship between the results presented in the social dimension and sustainability is disproportionate, as female equality in social inclusion presents results much lower than the



ideal levels in the proposed sustainability goals. However, this phenomenon is not exclusive to the dynamics of açai production. A study developed in the United States by Buck *et al.* (2021) showed the significant difference between the economic, environmental, and social dimensions, pointing to social segregation in various segments as a limiting factor in access to health, education, and housing, making it impossible to develop a sustainable society.

The indicator *Illiterate producers* undermine this dimension since a population with a higher level of education can adapt their actions to reduce adverse effects on the environment, such as understanding the risk of using pesticides on their crops, properly disposing of solid waste, and avoiding various types of pollution, including noise and visual pollution, and the dumping of waste into rivers (Moretto; Schons, 2007). Improvements in social conditions reflect the behavior of a social class (Moretto & Schons, 2007; Rico *et al.*, 2011). When this does not occur, sustainability presents a fragile balance. Social justice is an essential component of sustainability, not as a consequence, but as an interrelationship, in which it is necessary to be socially sustainable and have environmental security proportional to social well-being, in which the use of the environment produces income distribution for society and not impoverishment (Khanal *et al.*, 2021).

Although the results varied between favorable and unfavorable, no municipality was classified as *Critical* which can be considered an encouraging aspect since the social impact of açai production is high for the region. However, there is still much room for improvement to achieve more sustainable standards.

3.2 ENVIRONMENTAL DIMENSION

In this dimension, eight municipalities stand out as having a favorable performance, and only two towns have an unfavorable performance (Figure 3b). The score for Anajás reached the highest observed value, 74, considered Good. The municipalities of Igarapé-Miri and Barcarena had scores of 33.66 and 41.33, respectively, considered *Bad*. The municipalities of Bujarú, Bagre, Cametá, and Oeiras do Pará had values considered *Reasonable*. Given the level of importance of this sphere, it is possible to infer that the results are worrying, as they may compromise the ecosystem service that açai provides in the region. The environment, including natural resources, biodiversity, and ecosystem services, constitutes exhaustible natural capital (Mariosa *et al.*, 2019). Therefore, factors such as deforestation, expansion of agriculture, monocultures, and excessive land use result in adverse effects on the ecosystem (Silva *et al.*, 2003; Dala-Corte *et al.*, 2016; Lopes & Albuquerque, 2018; Selvaraj *et al.*, 2021).



Environmental impacts related to monoculture are often associated with removing native vegetation, impacting local and regional biodiversity (Green *et al.*, 2019).

It is possible to understand that municipalities with unfavorable indicators for sustainability are associated with negative environmental impacts, such as the indicator Total area harvested of açai (hectares), which may present areas with intensive management in the monoculture model. The adverse effects of monoculture vary greatly, among them the increase in the abundance of a single tree species (Silva *et al.*, 2023), impoverishment and decline of species in floodplain forests (Freitas *et al.*, 2015), soil erosion and decreased biodiversity (Nogueira *et al.*, 2005). Regarding the intensification of açai production in the northern region of Brazil, there is already evidence of environmental impacts, such as adverse effects on the ecosystem service of pollination (Campbell *et al.*, 2018). In addition, açai groves managed on dry land have lower productivity than açai groves managed in floodplain areas, their natural habitat (Coradin *et al.*, 2022). It is essential to highlight those areas with flooding variations are sensitive and have little resilience when they suffer disturbance from vegetation suppression (Carvalho *et al.*, 2021; Campbell *et al.*, 2018). Therefore, the larger the area of intensive açai cultivation, the greater the chance of environmental damage (Tagore *et al.*, 2018; Cunha & Costa, 2020).

The results related to the Açai Waste evidenced the high amount of waste generated due to açai exploration, as observed in the municipalities of Igarapé-Miri (28,764.80 tons), Cametá (5,399.20 tons) and Santa Izabel do Pará (3,882.40-ton), (Table 2). Considering this indicator from the point of view of sustainability, it was determined with an antagonistic relationship because, in addition to the large volumes of açai waste production, its disposal is generally carried out inadequately, compromising the quality of the environment. A study showed that in the capital of the state of Pará, Belém, approximately 56% of açai waste is dumped in landfills without any adequate treatment, generating environmental damage (Moreira & Souza, 2020).

The indicator *Non-use of pesticides* indicates an optimistic estimate in the ten municipalities evaluated about environmental integrity, emphasizing the city of Bagre, with the lowest pesticide use observed (Table 2). For this indicator, the data obtained from IBGE are related to all rural properties and not only properties producing açai. Generally, açai crops do not use pesticides (EMPRAPA, 2006). Even so, the use of agricultural pesticides in the Amazon has intensified as a strategy to ensure intensive production in crops of products that are more vulnerable to pests and diseases, increasing the risk of environmental contamination since pesticides are potentially polluting (Rico *et al.*, 2011).



The indicator *Do not receive technical assistance* has a negative expectation, being one of the main factors in the use of pesticides. Seeing that the producer can use pesticides without proper instructions, leading to an increase in risks to the environment since the quantities applied, for example, can be substantially higher than recommended by a technical expert (Monquero *et al.*, 2009; Rico *et al.*, 2011; Bento *et al.*, 2020). Therefore, environmental integrity is a determining factor for sustainable agricultural production because the lower the use of pesticides, the more positive impact on the health of the environment and the inhabitants of the region.

The *Permanent crops* indicator was considered beneficial for sustainability, as areas, where açaí is grown sustainably can generate benefits such as the regeneration of degraded areas through agroforestry, where it is possible to integrate açaí production with a diversity of other tree species, thus maintaining vegetation and maintaining the balance of the ecosystem. The management method determines the level of impact; in this case, *Permanent crops* were evaluated positively, as they generate forest conservation, such as when the açaí plantation is composed of a consortium in the agroforestry format (Tagore *et al.*, 2018; Veloz, 2020; Viana, 2020). Permanent crops contribute to continued production and are similar to native forests through agroforestry management (Tagore *et al.*, 2018; Viana, 2020). In Bolivia and Brazil, this was possible with products such as Brazilian nuts, cocoa, coffee, and crops introduced with other tree species (Vieira *et al.*, 2009). These practices represent a positive factor for the Amazon region, as they help combat deforestation, ensuring benefits such as maintaining carbon reserves (Villa *et al.*, 2015).

3.3 ECONOMIC DIMENSION

The Economic dimension (Figure 3c) showed unfavorable performance in nine municipalities, and only one had a favorable score; only the Barcarena municipality, with a score of 56.6, had the best performance considered *Reasonable*. Four municipalities presented results considered *Very Bad*. The lowest performances were in the municipalities of Anajás, Bagre, Limoeiro do Ajurú, and Oeiras do Pará, with a *Severe* classification, in which the lowest value was obtained for the municipality of Oeiras do Pará with a score of 19.8. The municipality of Cametá stood out for having the most significant number of farmers, approximately 12,227, without access to financial support for the development of agricultural production (Table 3). The lack of financing is a fact that may imply less adequate conditions for managed production, such as technical assistance, quality seedlings, and staff for sustainable production



management. Without financial assistance, all of these aspects become more difficult to execute, as the income from production is converted to expenses related to the açai cultivation process. Furthermore, the lack of support is a stimulus for agreements with açai processing companies, as this way, the financial return could be guaranteed more quickly (Rodrigues & Medeiros, 2023).

This dimension presented the most unfavorable results regarding sustainability (Figure 6 a), even with the growth and economic appreciation of açai. The economic circuit promoted by the açai production chain, from management to commercialization, involves several actors who benefit from this market, including the owners of the açai groves. These rural workers work in production at all stages, from harvesting to selling the produce, the açai intermediaries, resellers, and buyers (Veloz, 2020). However, it is possible to understand that the economic benefits are not proportionally distributed, given the results obtained.

In this dimension, low values of the indicators may be correlated with a lack of equity in income distribution due to the dynamics established in the açai production model until its final commercialization. Açai plantation owners direct their production to food processing companies, with pre-established purchase values but below the real economic value (Tágore *et al.*, 2018; Veloz, 2020). Other elements in this production chain are fruit collectors, owners of water transport (boats), and distributors (intermediaries), who resell the açai, all with inadequate remuneration, considering the value scales reached in the final export number (Tágore *et al.*, 2018; Rodrigues & Medeiros, 2023). For the region, one of the main impacts is the increase in the price of açai for consumption by the local population (Santana *et al.*, 2017; Ribeiro, 2016) because with the change in the market, the objective is to produce to supply supermarkets and companies in the food line of pulps and ice creams and also a high quantity for export, but this is not reflected equally in the production base of this food (Rodrigues & Medeiros, 2023; Ribeiro 2016).

The bioeconomy, in this case, may be similar to a trap; even though it has a sustainable purpose, the greater concentration of economic results may be associated with corporations and the export market (Magrach & Sanz, 2020), as the expectation is that by 2025 açai will generate US\$ 2.5 billion (Bérgamo *et al.*, 2022). The production of açai within the concept of fair-trade production is a challenge for municipalities with large fruit production in Brazil and other territories with similar problems. In Leticia, Colombia, the lack of health regulations is another factor that economically compromises the commercialization of açai (Veloz, 2020). Aspects such as low financing, lack of regulation for production, excessive exports, and absence of health regulation produce economic results that are far from the purposes of sustainability.

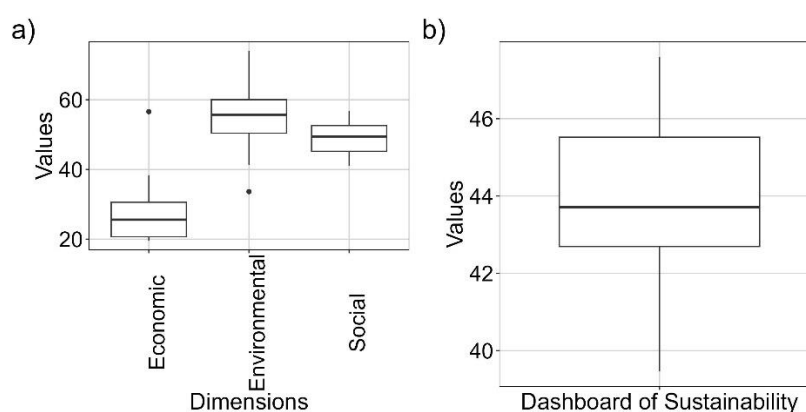


3.4 DASHBOARD OF SUSTAINABILITY PERFORMANCE

The Dashboard of Sustainability index results did not exceed the average score of 45, considered as medium level of sustainability (Figure 6). The current production model and the conditions of the municipalities evaluated cannot equally meet the socio-economic and environmental demands (Magrach & Sanz, 2020). Negative environmental impacts, low social justice, unequal income distribution, lack of health regulations, and lack of rules for production are factors that negatively affect the açai production chain, as observed through the results, which are well below average, that is, a high distance from achieving sustainability, which can be a threat mainly to the productivity of açai, and above all, to the Amazon biome.

Figure 3

Dashboard of Sustainability performance by a) Dimensions, b) overall assessment.



Source: author, 2023.

With the results, it was possible to establish a sustainability ranking among the municipalities with the highest açai production (Table 4). The municipalities of Barcarena and Anajás are in the top positions, with scores above 47 on the index. On the other hand, Abaetetuba and Igarapé Miri are in the bottom positions. Considering the overall result, the indicators that demonstrated the best performance are those that best contribute to meeting sustainability goals (Santos, 2019), such as *Non-use of pesticides*, *Receive technical assistance*, *Producers with higher education*, and *With financing for agricultural production*.

The result of 60% of the municipalities' classifications varied between Poor Very Poor and Severe which means that these municipalities have a sustainability performance that is far from being achieved, with emphasis on the economic dimension, which demonstrated the lowest performance among those analyzed. Only five municipalities demonstrated a classification considered as medium level. The city of Barcarena demonstrated the most



significant positive impact in the three dimensions, with an overall score of 47.59, considered as medium level.

Although it was possible to assess sustainability in these municipalities, the research encountered limitations in all dimensions evaluated, as there was a lack of data information in the official databases consulted, making it impossible to consider other indicators. For example, no municipality presented values for indicators of *Adequate treatment of solid waste*, *Quantity of urban solid waste* (MSW), and *Treated water*. These indicators could not be measured due to the lack of data in official databases, such as the SINIS (National Sanitation Information System) and SINIR (National Solid Waste Management Information System) databases, or the lack of service in the municipality.

Table 4

Sustainability ranking by the municipality assessed

Position	Municipality	Result	Classification
1st	Barcarena	47.59	Average
2nd	Anajás	47.36	Average
3rd	Cametá	45.8	Average
4th	Oeiras do Pará	44.68	Average
5th	Santa Isabel do Pará	43.72	Bad
6th	Limoeiro do Ajurú	43.48	Bad
7th	Bagre	43.7	Bad
8th	Bujaru	42.43	Bad
9th	Abaetetuba	40.95	Bad
10th	Igarapé Miri	39.47	Bad

Source: author, 2023.

For the state of Pará, this represents a threat to the Amazon biome since intensive açai management practices have already led to changes in floodplain areas, such as the conversion of these spaces to açai monoculture. In addition, a growing volume of açai waste, without adequate treatment, further aggravates the impact on the environment (Zarin *et al.*, 2001; Tagore, 2017; Campbell *et al.*, 2018; Moreira & Souza, 2020; Barbosa & Carvalho Junior, 2022). Floodplain areas are the natural habitat for açai cultivation, and when açai plantations are cultivated on dry land, they produce less fruit. Therefore, reducing naturally flooded areas would impact açai productivity, triggering a series of socio-environmental and economic losses for the region.

A previous study assessing more than 50 family agroecosystems in the municipality of Cametá-PA showed unsatisfactory results considering environmental, social, and economic aspects related to the management of açai palm groves in the region (Batista, 2013). Regarding



the ecological sphere, the author highlighted problems such as the absence of a basic sanitation system and solid waste treatment, in addition to the open-air burning of solid waste, which compromises the air and soil quality in the region.

The function of sustainability management is to present responses that propose a balanced, sustainable model in its various spheres. This is correlated with a more inclusive society, an equitable income distribution, and production chains assisted by regulation to sustain cultivation (Zeifert *et al.*, 2020; Keller & Lasch, 2022). However, when this does not happen, all the correlated dimensions tend to cause social, environmental, and economic damage of worrying proportions, as it compromises the entire subsistence mechanism of a region strongly associated with producing a financial asset, such as açai. In this sense, sustainability analyses with indicators tend to have an advantage in their applications precisely because they identify aspects that need improvements in their performance (Reis *et al.*, 2021). By evaluating responses to human impacts, it becomes possible to plan, understand the link and limits of nature and organize adjustments to achieve sustainability (Carvalho, 2014; Vieira, 2019), involving the producing community, the consuming community, and governance (Keller & Lasch, 2022).

Small and medium-sized municipalities, such as the municipalities evaluated in this study, are considered ideal for this type of analysis, as they facilitate the identification of factors that hinder the development of sustainability, management, and implementation of actions in policies to improve the performance of these indicators (Olivo *et al.*, 2021). Acting at municipal scales produces more localized responses, which can favor the improvement of sustainability indicators (Turra *et al.*, 2017; Hughes & Peterson, 2018; Maine *et al.*, 2022).

4 CONCLUSION

Considering all the results, no municipality presented an *Excellent* rating in any of the dimensions, which suggests that these municipalities need to improve their indicators to reach more sustainable levels. Instruments such as public policies can stimulate actions that help in paradigm shifts to improve these results. The environmental dimension presented the best performance in most municipalities; however, due to the lack of data, it was impossible to determine essential indicators in this dimension, such as aspects of basic sanitation in the municipalities. Those with better performance in the environmental dimension also showed good performance in the social or economic sphere. This result may be related to the state's increase in açai production.



Results such as those from this research can influence the mitigation of problems not only related to the performance of sustainability indicators but also highlight the importance of passing on municipal data to feed the official data system, which would improve indicator assessments, making monitoring even more precise in its results, seeking the final objective of achieving sustainability.

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