



SOCIOBIOECONOMIC EFFECTS OF THE TRANSITION OF COCOA GROWN IN AGROFORESTRY SYSTEMS TO FULL SUN IN THE AMAZON

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ABSTRACT

Objective: The goal of this research was to analyze the socioeconomic and environmental factors that define the technological transition in the microregion of Altamira.

Theoretical framework: Cocoa (*Theobroma cacao* L.) farming in agroforestry systems (AFS), which have always been the structuring base of the production chain, have now combined this base with the monoculture system also called full-sun cocoa farming system. The good practices used differ from the perspective of sustainable development: the AFS operates with social and environmental dimensions and the full-sun cocoa farming system operates with economic dimensions.

Results and conclusion: The four latent variables identified by Explanatory Factorial Analysis (EFA) indicated that the sociobioeconomic feasibility of cocoa farming with AFS is higher than that of Full-sun cocoa farming system, which is currently being implemented in the Trans-Amazon region. The conclusion is that cocoa farming with AFS dominated in the long-term generation of sociobioeconomic and may include new dynamics with the progress of certification and access to the carbon and ecosystems services market.

Research implications: How do the cocoa stakeholders notice the effects of cocoa farming transition from AFS to a combination with the Full-sun farming in the supply chain? The EFA was applied to a data sample with the stakeholders from cocoa chain to define the latent variables and to analyze the strengths and weaknesses of cocoa farming via AFS and Full-sun.

Originality/value: The Full-sun cocoa farming system is based only on the highest productivity resulted from the use of chemicals, mechanization and access to credit. The AFS presents higher yield, social inclusion, biodiversity preservation, and reduced greenhouse gases emissions. Therefore, the organization of producers, cocoa certification and access to the carbon market can make the cocoa farming in the Trans-Amazon region more competitive, inclusive, and sustainable.

Keywords: Bioeconomy, Sustainability, Family Farming, Cocoa Certification, Technology Pathway, Amazon.

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EFEITOS SOCIOBIOECONÔMICOS DA TRANSIÇÃO DO CACAU CULTIVADO EM SISTEMAS AGROFLORESTAIS PARA PLENO SOL NA AMAZÔNIA

RESUMO

Objetivo: O objetivo da pesquisa foi analisar os fatores socioeconômicos e ambientais definidores do processo de transição tecnológica em municípios da microrregião de Altamira.

Referencial teórico: A lavoura de cacau (*Theobroma cacao* L.) cultivada em sistemas agroflorestais (SAF), que sempre foi a base estruturante da cadeia produtiva, agora está combinando esta base com o sistema de monocultivo, também chamado de cacau a pleno sol. As boas práticas utilizadas são diferentes na perspectiva do desenvolvimento sustentável: o SAF opera com as dimensões social e ambiental e o pleno sol com a dimensão econômica.

Resultados e conclusão: As quatro variáveis latentes identificadas pela Análise Fatorial Exploratória (AFE) indicaram que o sistema de cacau em SAF ainda oferece viabilidade sociobioeconômica superior ao sistema de cacau a pleno sol, em processo de implantação na região da Transamazônica. A conclusão é que o SAF domina na criação de valor sociobioeconômico a longo prazo e pode adicionar nova dinâmica com o avanço da certificação e acesso ao mercado de carbono e serviços ecossistêmicos.

Implicações da pesquisa: Como os grupos de interesse no cacau percebem os efeitos da transição do cacau em SAF para uma combinação pleno sol e SAF no suprimento da cadeia? A AFE foi aplicada a uma amostra de dados com os grupos de interesse da cadeia do cacau para a definição de variáveis latentes e análise dos pontos fortes e fracos do cacau em SAF e a pleno sol.

Originalidade e valor: O sistema de produção de cacau a pleno sol está ancorado apenas na maior produtividade resultante do uso de insumos químicos, mecanização e acesso a crédito. O SAF apresenta rentabilidade segura, inclusão social, preservação da biodiversidade e redução das emissões de gases de efeito estufa. Portanto, a organização dos produtores, a certificação do cacau e o acesso ao mercado de carbono, podem tornar a cacauicultura da Transamazônica mais competitiva, inclusiva e sustentável.

Palavras-chave: Bioeconomia, Sustentabilidade, Agricultura Familiar, Certificação do Cacau, Trajetória Tecnológica, Amazônia.

EFFECTOS SOCIOBIOECONÓMICOS DE LA TRANSICIÓN DEL CACAO CULTIVADO EN SISTEMAS AGROFORESTALES A PLENO SOL EN LA AMAZONIA

RESUMEN

Objetivo: El objetivo de esta investigación fue analizar los factores socioeconómicos y ambientales que definen la transición tecnológica en la microrregión de Altamira.

Marco teórico: El cultivo de cacao (*Theobroma cacao* L.) en sistemas agroforestales (AFS), que siempre han sido la base estructural de la cadena de producción, ahora han combinado esta base con el sistema de monocultivo también llamado sistema de cultivo de cacao a pleno sol. Las buenas prácticas utilizadas difieren de la perspectiva del desarrollo sostenible: la AFS opera con dimensiones sociales y ambientales y el sistema de cultivo de cacao a pleno sol opera con dimensiones económicas.

Resultados y conclusión: Las cuatro variables latentes identificadas por el Análisis Factorial Explicativo (AFE) indicaron que la factibilidad socioeconómica del cultivo de cacao con SAF es mayor que la del sistema de cultivo de cacao a pleno sol, que actualmente se está implementando en la región Transamazónica. La conclusión es que el cultivo de cacao con SAF dominó en la generación a largo plazo de la sociobioeconomía y puede incluir nuevas dinámicas con el progreso de la certificación y el acceso al mercado de servicios de carbono y ecosistemas.

Implicaciones de la investigación: ¿Cómo perciben las partes interesadas del cacao los efectos de la transición de la agricultura de cacao de AFS a una combinación con la agricultura a pleno sol en la cadena de suministro? La EPT se aplicó a una muestra de datos con los actores de la cadena del cacao para definir las variables latentes y analizar las fortalezas y debilidades del cultivo de cacao a través de AFS y Full-sun.



Originalidad/valor: El sistema de cultivo de cacao a pleno sol se basa únicamente en la mayor productividad resultante del uso de productos químicos, la mecanización y el acceso al crédito. El AFS presenta mayor rendimiento, inclusión social, preservación de la biodiversidad y reducción de emisiones de gases de efecto invernadero. Por lo tanto, la organización de los productores, la certificación del cacao y el acceso al mercado de carbono pueden hacer que la agricultura de cacao en la región Trans-Amazónica sea más competitiva, inclusiva y sostenible.

Palabras clave: Bioeconomía, Sostenibilidad, Agricultura Familiar, Certificación de Cacao, Vía Tecnológica, Amazonia.

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1 INTRODUCTION

Cocoa production in the state of Pará adopts the sustainable technology of Agroforestry Systems (SAF), considered suitable for the edaphoclimatic conditions, social inclusion of family farmers and preservation of the biodiversity of the natural ecosystems of the Amazon, with superior economic, social and environmental results than monoculture systems (Silva *et al.* , 2017; Almeida, 2019; Santana, 2020; Oliveira *et al.* , 2023).

The state of Pará, with production of 138,471 tons of cocoa beans (*Theobroma cocoa* L.) and a production value of R\$ 2,009,789 thousand, equivalent to 46.76% of production and 43.37% of the value of Brazilian production (IBGE, 2024). With a 5.15% drop in production and 10.37% in productivity between 2022 and 2023, the state of Pará lost its first position as the largest cocoa producer in Brazil to the state of Bahia. The Altamira microregion, in turn, contributed 79.05% and 89.61%, respectively, of the production and value of cocoa production in Pará in 2023 (IBGE, 2024).

In the last decade, some farmers, seeking technological innovations to mitigate the barriers to the formation of new cocoa production systems, have tested the systems that are evolving in the states of Bahia and Espírito Santo, which use high-yield clones grown in full sun (AIPC, 2022; Coslovsky , 2023). Due to the higher yield per hectare than the AFS, the full sun system has been gaining the support of producers and some of them have started to replace the older AFS. Other factors increase support because it is a system that uses chemical inputs, mechanization and access to credit, which are adapted to large-scale production (Kongor *et al.* , 2018; Folhes & Sena, 2023; Santana *et al.* , 2023). However, the social and environmental impacts present disadvantages in relation to SAF, dimensions that are required by national and international chocolate consumers, especially when the raw material originates from the Amazon (Santana, 2021; Santana *et al.*, 2024a).



This issue surrounding the potential transition of cocoa produced in AFS to the dominance of full-sun production is currently under discussion regarding its economic, social, and environmental effects. For now, arguments about full-sun cocoa focus on the economic dimension, while supporters of AFS focus on the social and environmental dimensions. In order to contribute with more knowledge and information for the understanding of this potential problem, the research sought to answer, based on the perception of the agents that directly and indirectly act in the cocoa chain of the Trans-Amazonian region, the following questions: what are the main factors that differentiate full-sun cocoa from AFS and that can trigger its dominance in the Trans-Amazonian region? Can the certification of cocoa farms, the carbon and environmental services market, and social inclusion maintain the dominance of AFS cocoa production in the Trans-Amazonian region?

The objective of the research was to analyze the socioeconomic and environmental factors of the transition from cocoa cultivation in agroforestry systems to full-sun monocultures in the municipalities of the Transamazônica region.

2 THEORETICAL FRAMEWORK

Cocoa cultivation in AFS from the 1970s onwards adopted the felling of native forest to initiate shaded planting with banana and other forest species, according to Folhes & Serra (2023), with the recommendation of the Executive Commission of the Cocoa Farming Plan (CEPLAC). The adoption of this production system required investment credit and funding to make the production plan viable in order to include small farmers and guarantee the supply and well-being of their families.

This technology, even with the participation of CEPLAC in guiding the management and use of hybrid cocoa seeds, the yield per hectare in the last 25 years has evolved at a rate of 1.44% per year, while the area has grown at a rate of 6.91% per year, maintaining the process of deforestation for new crops and, more recently, the use of degraded pasture areas (IBGE, 2024; Coslovsky, 2023). On the other hand, the production of cocoa in SAF has attracted the interest of certifying companies to acquire almonds produced in systems that meet the dimensions of sustainable development, through the use of more productive, inclusive and sustainable good practices, in order to differentiate the product to serve consumers willing to pay prices high enough to compensate for social and environmental opportunity costs (Kroeger *et al.*, 2017; Pião *et al.*, 2020; Santana, 2021; Santana *et al.*, 2024; Santana *et al.*, 2025).



In line with sustainability, the Federal Government created the Green Seal for Amazonian cocoa ([Law No. 14,877, of June 4, 2024](#)), with a view to certifying producers who cultivate cocoa in AFS systems and contributing to reducing the barriers created by price formation indexed to *commodity exchanges* , whose information asymmetry increases the irrationality of family farmers' decisions. With this, although cocoa production in AFS contributes to maintaining biodiversity, regulating the climate and greenhouse gas emissions, and including local labor in relation to monocultures , the barriers to access to credit, technical assistance, and market information cannot prevent deforestation for the inclusion of new areas (Kroeger *et al.* , 2017; Brainer , 2021; Santana, 2021; Santana *et al.* , 2024).

In the perception that AFS is a natural barrier to increasing cocoa yield per hectare, due to the scarcity of credit for the use of sustainable technologies and innovations, some producers are adopting the use of full-sun cocoa cultivation, with a view to reducing dependence on labor and increasing the scale of production with access to credit for the use of chemical inputs and crop mechanization (Ricci *et al.* , 2006; Folhes & Serra, 2023). This is occurring despite the warning that monoculture makes the system more susceptible to outbreaks of specific diseases and pests and causes losses in the quantity and quality of the product and income (Kongor *et al.* , 2018; Padovan *et al.* , 2022; Santana *et al.*, 2025). Furthermore, as occurred in Ghana and Côte d'Ivoire, cocoa producers in AFS, without access to technical assistance and credit, when migrating to full-sun cocoa, face new dependencies on chemical inputs, operate in the face of climate risks and higher prices, and decreased profitability with the increase in social opportunity costs and the standing forest (Ruiz *et al.* , 2023; Santana *et al.* , 2023, 2024; Oliveira *et al.* , 2023).

3 MATERIAL AND METHODS

The study area covered the municipalities of the Altamira microregion, also known as the Trans-Amazonian cocoa hub (Mendes, 2009; Santana *et al.*, 2025). It is in the municipalities of this microregion where the full-sun cocoa production system is advancing through the engagement of cocoa producers in AFS and other producers interested in the recovery of degraded pastures . For now, the adoption of the full-sun cocoa production system is anchored in the potential economic return to be generated by increasing yield per hectare and opportunities for access to credit to expand the scale of production with the use of chemical inputs, mechanization, and reduced dependence on labor. However, factors associated with biodiversity preservation, regulation of climate effects and the incidence of pests and diseases,



inclusion of labor and the opportunity to increase the number of certified farms and participation in the carbon and ecosystem services market were not taken into account to support the strategic decisions of the agents involved in the cocoa value hunt. At this point, research in the study area can be justified by the contribution of information and knowledge about the advantages and disadvantages of building this new growth trajectory based on two antagonistic production systems.

The sample was designed to obtain information not included in the first sample from the agents participating in the entire cocoa chain and not just the producers. Data collection was done using an interactive digital technological resource, the *KoBoToolbox software form*, which allowed 67 responses in data collection via smartphone and automatic tabulation in different formats, carried out during the III Symposium on Agroforestry Systems with Cocoa, which took place on June 12 and 13, 2024 in the city of Altamira/PA, and aimed to better qualify the demands in relation to perceptions, motivations and effects of the transition of cocoa production systems with the participants of this technical-scientific event whose target audience was cocoa farming actors, namely: researchers, professionals, students, farmers and interested parties.

The qualitative variables included in the *Survey* were organized on a *Likert scale* with the following dimensions (low, medium and high): 1. How do you evaluate your knowledge about SAF - Cavalia SAF; 2. How do you evaluate your knowledge about cocoa in full sun - Cavalia Psol; 3. Knowledge and experience is greater in SAF or Full sun - C SafxPsol; 4. System offers greater sociobioeconomic security in the long term - Mseg SBE Long Term; 5. System more sensitive to pests and diseases - S+PgDoença; 6. Biosocioeconomic viability of SAF - VBSE SAF; 7. Viability of the Psol system is greater than SAF - Vpsol greater than SAF; 8. Recommends replacing SAF with full sun - Recommends SAF; 9. Recommends hybrid/cloned in SAF/ Psol - Recommends H SAF/ Psol.

3.1 EXPLORATORY FACTOR ANALYSIS

Data from both samples were submitted to SPSS (*Statistical Package for Social Sciences*), for the application of the Exploratory Factor Analysis (EFA) technique, which allows the analysis of correlations of quantitative and/or qualitative variables to define latent variables capable of representing complex phenomena of the real world through multivariate statistical models (Santana, 2020; Santana et al., 2025). The latent variables or factors can represent the economic, ecological and social characteristics of the agroforestry and full-sun systems of cocoa grown in municipalities of the Trans-Amazonian cocoa hub.



The application of EFA requires the standardization of variables through the correlation matrix associated with the explanatory variables. The highest correlations are grouped as an indication of the latent dimensions that are still unknown, but which bring together the theoretical and real attributes to represent the phenomena to be studied (Dillon & Goldstein, 1984). Therefore, the latent factors identified through factor analysis can summarize the set of information dispersed in the data matrix of the sampled variables in a smaller subset, without significant loss of information, to explain the phenomenon studied (Santana *et al.* , 2018; Santana, 2020; Souza *et al.* , 2024; Oliveira *et al.* , 2024).

In exploratory factor analysis, each factor is defined by a vector of significant factor loadings, associated with the capacity of each variable to explain the factor and of this to explain part of the total variance of the data (Hair Jr. *et al.* , 2010). Therefore, it is possible to associate these dimensions with situations experienced by the arrangement of characteristics linked to each variable, according to their alignment with the latent dimensions as extracted by the factor analysis model (Santana, 2020).

In the specification of the EFA model, according to Dillon & Goldstein (1984), it is assumed that each observed variable is a linear combination of the extracted latent factors, such that each random variable $y_i \in \{1, ..., N\}$ belongs to a homogeneous population with mean μ_i , being structured as in equation 1.

$$Y_i = \Psi_y F_i + \mu_i + e_i, (i = 1, 2, ..., n), \quad (1)$$

Where:

Y_i is the set of explanatory variables included in the model, Ψ_y is the matrix of factorial loads or weights, F_i is the vector of latent factors and e_i is the vector of random errors. Independence is assumed between F_i and e_i (Santana *et al.* , 2018). The first term on the right-hand side of the equation represents the covariance of the common factors, the second is the mean and the third is the covariance attributed to the error.

The application of the EFA technique requires the adequacy of the data sample. Thus, the variables must present a matrix with significant correlations and a determinant different from zero, together with technical and statistical significance of the Bartlett and Kaiser-Meyer-Okin (KMO) tests and the analysis of consistency and reliability by the level of explained variance and factor loadings, as they correspond to statistical procedures that allow assessing



the adequacy of the specified EFA model (Hair Jr. *et al.*, 2010; Ferreira *et al.*, 2016; Oliveira *et al.*, 2024; Santana *et al.*, 2025). The number of factors required to describe the data was determined by the principal component analysis method, which recommends the extraction of those with explained variance greater than one.

Two different samples were analyzed on the topic of the transition of cocoa grown in agroforestry systems to the full-sun cocoa system. The sample consisted of 67 interviewees with knowledge on the research topic and met the requirements of 95% confidence and 11.6% error in relation to the universe of cocoa producers in the study area.

4 RESULTS AND DISCUSSION

Table 1 shows the selected variables, the significant factor scores and the tests that indicate the adequacy of the data sample for factor analysis, such as the KMO with a value of 0.542, higher than the minimum acceptable of 0.50, and the Bartlett sphericity test with a p -value < 0.0001 . The sample size of 67 observations ensures 7.4 observations per variable, considered adequate for estimating factor loadings.

All variables presented commonalities above 0.50, which is necessary to validate the participation of the variables in the definition of the factors. The practical and statistical significance of the loadings was met, since all of them reached a value equal to or greater than 0.608 for the sample size. The factor loadings are all significant, with the lowest value being equal to 0.608, associated with Factor 4. This indicates that 36.97% ($= 0.608 \times 0.608$) of the total variance of the variable - SAF/ Psol Recommends, was explained by the respective factor.

Table 1

varimax orthogonal rotation with the defining variables of the extracted factors.

Variable	Factor				Commonality
	Factor 1	Factor 2	Factor 3	Factor 4	
Mseg SBE Long Term	0.803	0.111	-0.132	-0.058	0.678
SafxPsol Knowledge	0.741	-0.281	0.058	0.042	0.633
S+PgDisease	-0.020	0.823	-0.280	0.053	0.759
VBSE SAF	-0.068	0.741	0.335	0.031	0.667
Cavalia Psol	0.132	-0.172	0.823	0.099	0.733
Cavalia SAF	-0.310	0.380	0.710	-0.096	0.754
VPsol greater than Saf	0.255	0.031	0.180	0.769	0.689
Psol recommended	-0.491	0.139	-0.230	0.642	0.726
Recommends SAF/ Psol	0.514	0.052	0.036	-0.608	0.638
Eigenvalue of variables	1,883	1,515	1,479	1,401	6,278
Variance explained (%)	20,926	16,830	16,437	15,563	69,756
Adequacy of the sample to the EFA and reliability of the model	KMO statistic = 0.542 Bartlett test : 99.168 ($p < 0.0001$)				



Based on these practical and statistical results, the EFA model was well specified and the results can be considered consistent with the present study. Four latent variables or factors were identified and extracted, duly ordered by the degree of explanation of the total variance, defined after the *Varimax orthogonal rotation*. The factors explained 69.76% of the total variance of the data (Table 1).

Factor 1 explained 20.93% of the data variance and was composed of two qualitative variables described in the methodology: Mseg SBE in the long term and Knowledge of SAF/ Psol (Table 2). Based on the factor loading score of the first variable, this factor can be called **SAF is sustainable**, since, in the perception, knowledge and experience of the interviewees, SAF offers greater sociobioeconomic sustainability in the long term for family farmers. In this case, 95.52% of the interviewees stated that cocoa in SAF, according to the knowledge and experience accumulated on the competitive performance of cocoa in full sun, presents greater long-term security, especially with the opportunity to participate in the voluntary carbon and environmental services market. In addition, the knowledge about the environmental and social differential accumulated over the years by the agents working in family farming allowed confirming that cocoa in SAF is sustainable.

Factor 2 explained 16.83% of the remaining variance in the data and represents the contributions of two variables: S+Pg Disease and VSBE SAF. Due to the magnitude of the factor loadings, the factor was called the **Safe Profitability System** (Table 2). In the perception of the interviewees, the SAF is less susceptible to disease (62.69%) than the full sun system (37.31%). Likewise, 64.61% of the interviewees stated that the SAF has a high VBSE, compared to 11.29% for full sun cocoa. According to Santana (2021), cocoa in the traditional system of the Trans-Amazonian cocoa hub is a crop with low socio-bioeconomic return, but it is safe and highly liquid in the local market. This liquidity, in the perception of most interviewees, is high due to the low socio-environmental and climatic risks of the system.

Factor 3, composed of the variables Cavalia Psol and Cavalia SAF, explained 16.44% of the data variance and was called **Technical knowledge about cocoa** (Table 2). The interviewees expressed their knowledge about cocoa cultivation systems in SAF and in full sun. Naturally, high and medium knowledge about SAF was 80.6%, given the tradition in this crop that built human capital by aggregating experience, tacit knowledge and formal knowledge, together with the system management capacity. On the other hand, the knowledge revealed about cocoa in full sun, with 58.21% medium and high, reveals the ease of those involved in the activity, in the aspects of greatest similarity with the work in other permanent crops, use of machines and chemical inputs, given the short time of implementation of the crop.



Factor 4 represents the characteristics of the variables Viability of full sun, greater SAF, Recommends the transition from SAF to full sun and Replacement of hybrid in SAF and in full sun, which explained 15.56% of the data variance. The factor can be called **Transition of cocoa from SAF to full sun** (Table 2). This factor has the lowest explanatory power and importance revealed by the EFA model. The variable indicating the greater viability of SAF in relation to full sun had the agreement of 58.21%. On the other hand, the recommendation of the transition from SAF to full sun, with a negative sign of the factor loading, received the agreement of only 16.42% of the respondents. Regarding the inclusion of hybrid or cloned cocoa in the systems, 86.57% were in favor. Thus, the transition still requires more knowledge than that revealed in this research by the protagonists with the greatest knowledge about the cocoa chain. The fact is that cocoa grown in full sun caused an expansion of the area, but presented a drop in productivity and, in turn, in the quantity produced, from 2021 onwards (IBGE, 2024).

At this point, SAF advocates, by preserving agrobiodiversity and adapting to the tacit knowledge rooted in the culture, traditions and experiences of family farmers, contribute to the construction of social capital and human capital, aiming to guarantee subsistence in the face of low crop yields (Kroeger *et al.* , 2017; Santana, 2021; Santana *et al.*, 2025). In effect, the SAF loses competitive advantage to the defenders of the full sun cocoa system due to the greater degree of suitability for medium and large producers, who implement the system in degraded areas, access credit without major impediments to deal with the barriers of land and environmental legislation (Barhttary *et al.* , 2020; Ruf , 2011; Santana, 2021; Coslovsky , 2023).

This transition trend towards full-sun cocoa may lose strength in the medium and long term with the consolidation of the voluntary carbon and ecosystem services market, creating a competitive advantage for SAF systems, by increasing the net present value through the sale of environmental services and applying a sustainable price for certified cocoa beans (Santhyami & Suparti , 2023; Santana *et al.* , 2024; Santana *et al.* , 2024a).

4.1 COMPARATIVE ANALYSIS BETWEEN COCOA IN AFS AND FULL SUN

The results of Figure 1 on the socio-bioeconomic characteristics of the cocoa systems in AFS and cocoa in full sun show that there is strong evidence of socio-environmental competitive advantages for cocoa in AFS that are difficult to overcome, under the current and future conditions of the national and international consumer markets, by cocoa in full sun. The differences in the economic aspects of productivity and costs of cocoa in full sun should only

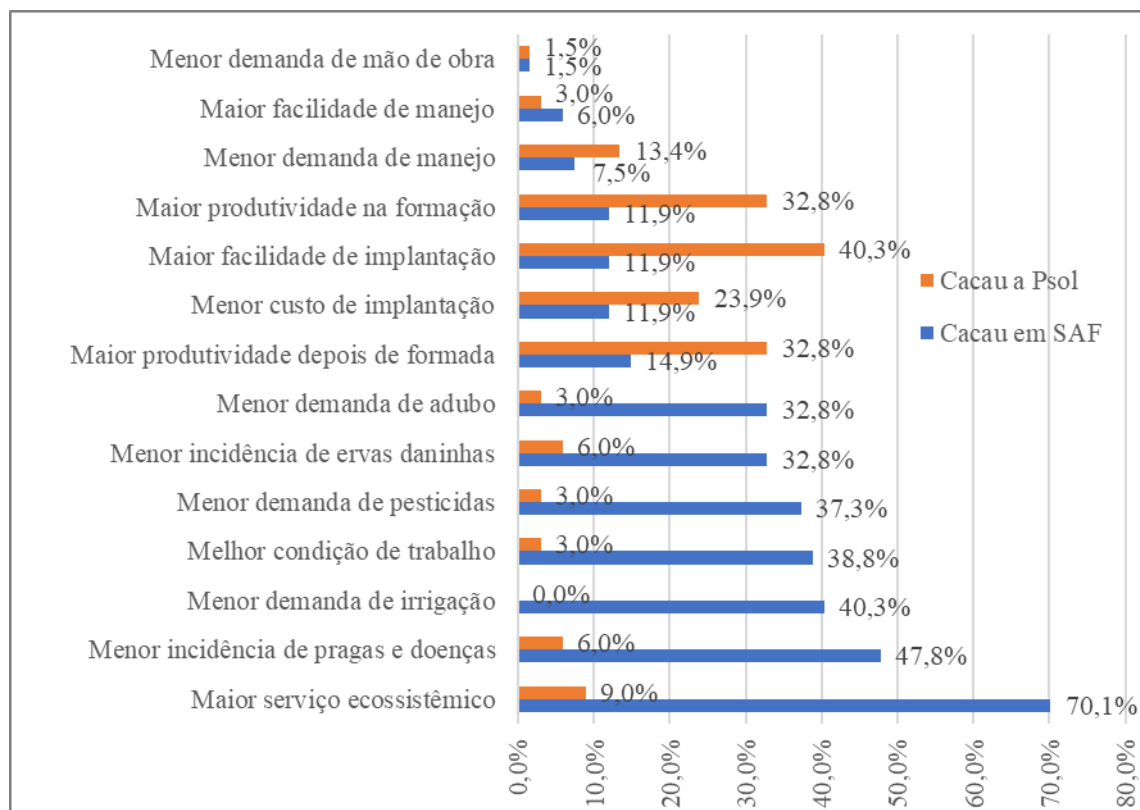


be absorbed as opportunities for the incorporation of technologies and innovations in genetic material, crop management, cost management and climate risk management to gain new growth dynamics with social inclusion and environmental sustainability, especially with the opportunity to participate in the voluntary market for environmental services and the certification of products with these differentiated characteristics.

The results in Figure 1 indicate that the human capital built throughout the history of cocoa cultivation in AFS in the Trans-Amazonian, the biodiversity of flora and fauna, well-being at work, the ecosystem services of environmental regulation, culture and ecosystem formation, together with other socioeconomic benefits that it generates over a long cycle, confer comparative and competitive advantages in land use and marketing for cocoa in AFS (Knöblsdorfer *et al.* , 2021; Oliveira *et al.* , 2023; Santana *et al.* , 2023).

Figure 1

Comparison between the productive characteristics of cocoa systems in SAF and cocoa in full sun of the Transamazônica cocoa hub, from the producers' perspective.



These advantages clash with works that, trying to participate in the potential benefits disseminated by those who believe in the greater profitability of full-sun cocoa as a promising alternative in the Transamazônica (AIPC, 2022; Santos & Silva, 2017), due to the limitation of

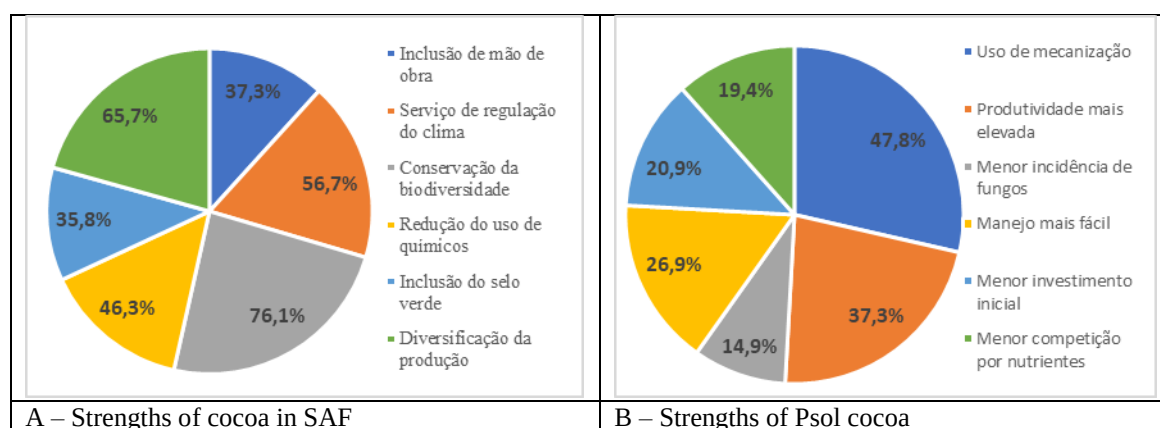


the holistic view on the opportunities that cocoa in SAF can build with the organization of producers in cooperatives to adopt good practices, aiming to increase the scale of production, add quality and value to the product and integrate SAF into the ecological tourism of the Transamazônica cocoa hub (Nunes & Bastos, 2018; Nascimento *et al.*, 2019; Folhes & Serra, 2023; Santana *et al.*, 2024a).

In the perception of the interviewees, it is observed that the basic difference to guide the decisions of the agents in the investment between the two systems is visibly anchored in the environmental and social dimensions for cocoa in AFS, forces that contribute to the performance of cocoa crops, but remain hidden in the analyses on sustainable development, and in the economic dimension for cocoa in full sun (Figures 2 and 3). In the strong points, the focus on the environmental dimension of cocoa in AFS was revealed by a strong percentage of the interviewees, the emphasis on environmental services of climate regulation, adoption of good practices to diversify products, conserve biodiversity, reduction of the use of chemical inputs and the social service through the inclusion of labor (Figure 2A).

Figure 2

Comparison of the strengths of the cocoa systems in SAF and cocoa in full sun of the cocoa hub of Transamazônica.



In the full-sun system, only the strong points related to the economic dimension were identified by the interviewees, with a percentage lower than 50%. The most significant were productivity and the use of mechanization, both relevant for *commodities* that are made viable by the scale of production (Figure 2B).

Regarding the points identified as weaknesses by the interviewees, unlike what occurred with the strengths, the focus was on the economic dimension for cocoa in SAF, with percentages below 50% of the 67 respondents (Figure 3A). In cocoa in full sun, the weakness

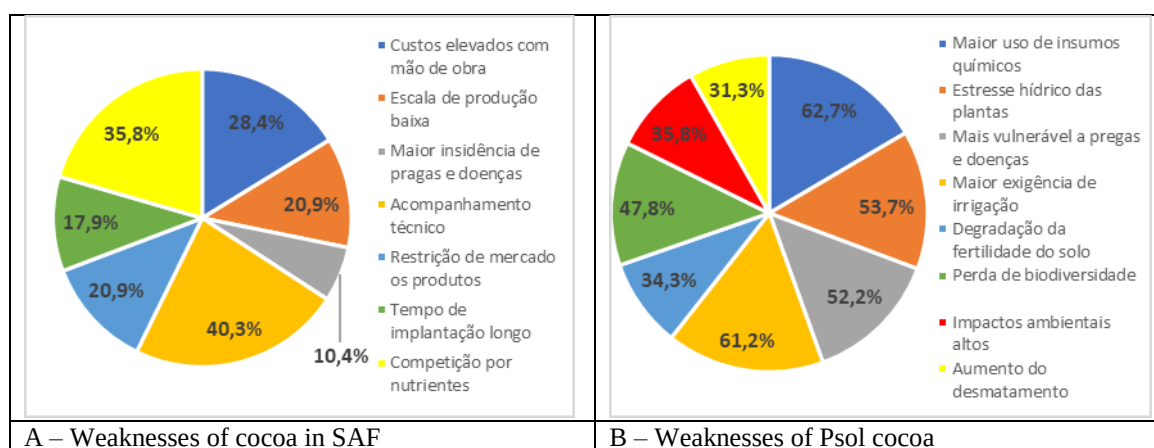


was concentrated in the environmental dimension, with the agreement of more than 50% of the interviewees (Figure 3B).

In the balance of the effects of the variables presented in Figures 2 and 3, the process of expansion of cocoa in full sun continues to be dominated by the cocoa system in agroforestry systems, due to the socio-environmental opportunities associated with the natural ecosystem of the Amazon, it can reach a new pace of development. Thus, the studies by Saadun *et al.* (2018), Kroeger *et al.* (2017), Bakhtary *et al.* (2020), Santana (2020; 2021), Musure *et al.* (2023) and Santana *et al.* (2023; 2024a) indicate that cocoa AFS should gain new dynamics with the adoption of more productive, inclusive and sustainable good practices in order to meet the objectives of sustainable development. The opportunity scenario is emerging with the evolution of the carbon and environmental services market and the inclusion of social opportunity costs and natural assets in the cash flow and the definition of a socio-environmental equilibrium price for cocoa beans, together with the adoption of the green seal (Law No. ^{12,877}/2024) and other producer certification systems (Gomes *et al.* , 2024; Santana *et al.* , 2024b).

Figure 3

Comparison of the weaknesses of the cocoa systems in SAF and cocoa in full sun of the cocoa hub of Transamazônica.



The resulting vector of the four latent variables indicates that the AFS cocoa system still offers superior socio-bioeconomic viability to the full-sun cocoa system, which is currently being implemented to dominate the cocoa economy in the Trans-Amazonian cocoa hub. The results indicate that only the variable of higher yield per hectare is leading beginner producers to experiment with full-sun cocoa planting, with due caution in the transition process. The support points for this behavior are associated with experience and knowledge about AFS cocoa and the safe, albeit low, return on the long-term trajectory followed.



Agents in the cocoa value chain realize that full-sun farming moves away from adherence to the value of the Amazon forest assessed by the carbon and ecosystem services market (Santana *et al.* , 2024), that cocoa in SAF has already been gaining part of this recognition with producer certifications for the differentiated qualities of cocoa beans and, more recently, by the Decree Laws that instituted the program to strengthen family farming cooperatives (DL No. ^{12,088}/2024), the productive forest program (DL No. ^{12,087}/2024) and the Law that created the green seal for Amazon cocoa (Law No. ^{12,877}/2024).

In this context, medium and long-term advantages require the implementation of innovation in the process, product and management of the SAF system, with a focus on restructuring the cash flow to contemplate the social, environmental and economic dimensions and to define a sustainable price in cocoa bean transactions (Santana *et al.*, 2023). In this line, economies of scale can be obtained by organizing into cooperatives and economies of scope by adding value to the bean and other products such as butter to certify farms with price quotations that compensate for socio-bioeconomic costs (Santana, 2020; Iddrisu *et al.* , 2020; Santana *et al.*, 2025).

4.2 SOCIOBIOECONOMIC SUSTAINABILITY OF THE COCOA CHAIN

socio-bioeconomic sustainability index The spatialized analysis of the cocoa value chain in the state of Pará shows the contribution of the economic (gross value of production), social (formal employment) and environmental (annual deforestation rate) dimensions to development (Santana, 2021; Santana *et al.* , 2024c). The socio-bioeconomic sustainability index , which results from the effects of the economic, social and environmental dimensions, hides the individual contributions in the composition of the index. Thus, it is observed that there is high sustainability in six municipalities in the study area. However, five present high sustainability dominated only by the social dimension, two with economic and social sustainability and no municipality with environmental sustainability.

Therefore, we warn against studies based on multivariate indicators that do not open up the methodology so that the contributions of each variable can be visualized. Therefore, it is important to analyze the scope of the concept of inclusive and sustainable value chains (Santana, 2021; Santana *et al.* , 2024c) to understand the degree of harmony between the forces that define sustainable development. With this, activities can be planned to reduce inequalities between the economic, social and environmental dimensions.



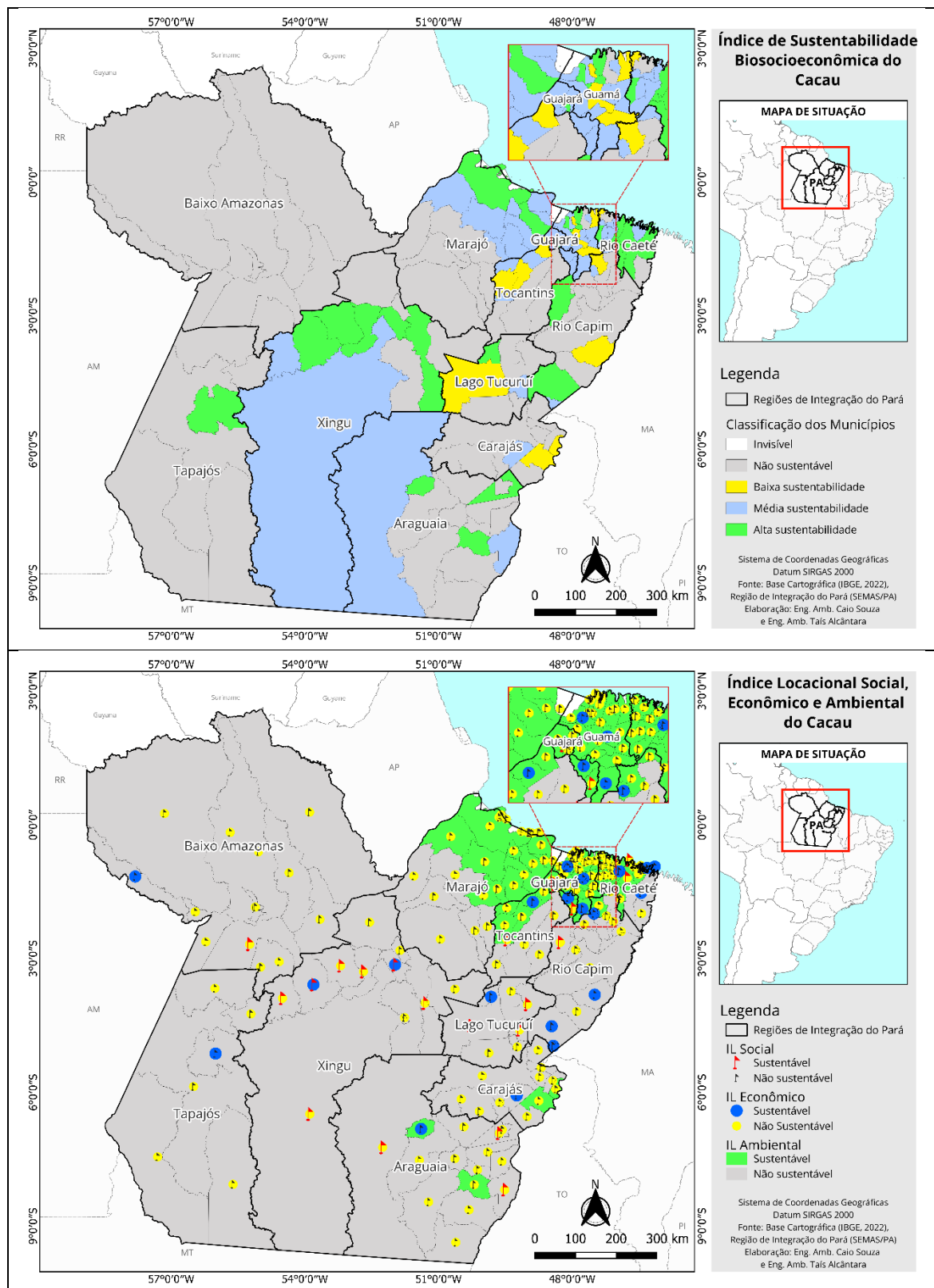
It is noted that there is an evident imbalance between the three forces of sustainable development in the same municipality. Therefore, the challenge of making theoretical knowledge about local development, as didactically elaborated by Costa (2024), real, given the real conditions of development planning, investment, technology and innovation, human capital, social capital, information, entrepreneurial capacity and efficient governance, is a very long-term possibility.

Combining the results presented in Figures 2 and 3 with those in Figure 4, it follows that cocoa in AFS should increase the socio-bioeconomic return through the use of more productive and sustainable good practices, starting with cocoa seedlings genetically improved in quality attributes and resistance to pests and diseases, adjusting the management of AFS with the inclusion of forest species of high commercial and ecological value (species of the biome with high power to sequester and store carbon) and less shade, organization in cooperatives with professional and transparent management, fermentation of almonds and minimal processing to differentiate and certify the products. In cocoa in full sun, forest essences should be included in the system and biofertilizers should be used to reduce the costs of chemical inputs and use good practices to recover degraded pasture areas and increase the inclusion of local labor to participate in the voluntary carbon market. Therefore, it is possible for systems to evolve without the need for replacement and worsening of market failures due to the effects of asymmetric information and limited rationality in investment decisions and commercial transactions in local, national and international markets.



Figure 4

Sociobioeconomic Sustainability Index and Social, Economic and Environmental Locational Indices of the Inclusive and Sustainable Cocoa Value Chain, State of Pará, 2022



Source: Santana et al. (2025). Xingu includes the municipalities of the cocoa region of Transamazônica.



5 CONCLUSIONS

The results of the research contributed to the knowledge about the latent variables that are guiding the decisions of producers in the adoption of SAF systems, full sun or the integration of the two systems. The exploratory factor analysis model allowed the identification of four latent dimensions, or factors, and explained 69.76% of the total variance of the data. The most important factors were: SAF is sustainable (20.93%); Secure sociobioeconomic profitability (16.83%); Traditions and knowledge about SAF (16.44%); and Transition from the SAF system to full sun (15.56%). These results indicate that the interest in full sun cocoa is anchored in the opportunity to access credit, private technical assistance to guide the use of inputs and mechanization aimed at the recovery of degraded pasture areas and avoiding deforestation even in the short term.

The resulting vector of the four latent variables indicates that the SAF cocoa system still offers superior sociobioeconomic viability to the full-sun cocoa system, which is currently being implemented in the Trans-Amazonian cocoa hub. The conclusion is that the SAF dominates in the creation of long-term sociobioeconomic value and can add new dynamics with the advancement of certification and access to the carbon and ecosystem services market. The full-sun system is anchored only in higher yields through the use of inputs, mechanization, and access to credit anchored in the short term.

The research is limited by the availability of information on the results of the full-sun system generated in the largest producing countries, whose results frustrated the government plans of Ghana and Ivory Coast, due to problems combining climate effects with the incidence of pests and diseases. In the state of Bahia, the full-sun cocoa system, which has been in development for a longer time, has not yet changed the average yield per hectare in the state, given that only four municipalities have a yield above 900 kg/ha (IBGE, 2024).

In this context, it is suggested that studies be carried out in greater depth to generate more information on the impacts of cocoa production systems on technologies and responding to opportunities offered by the market for products that use good practices that are more productive, inclusive and sustainable in the Amazon.

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