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CORPORATE SOCIAL RESPONSIBILITY IN THE SUGARCANE AND ENERGY SECTOR IN SÃO PAULO: A FUZZY ANALYSIS OF MACROSSOCIAL RELATIONS

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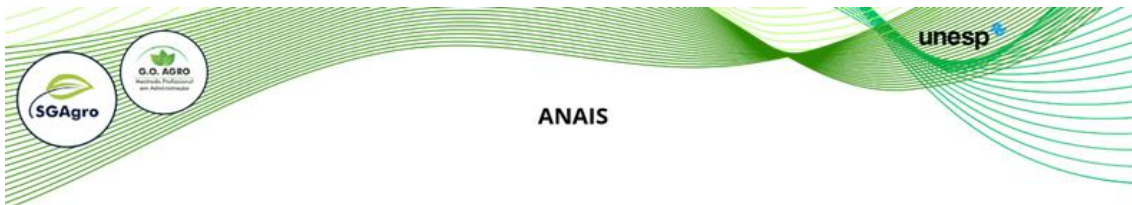
RESUMO: O setor sucroenergético brasileiro, concentrado em São Paulo, é estratégico, com raízes históricas e evolução tecnológica contínua. As usinas desempenham papel central no desenvolvimento regional, gerando emprego e renda, mas também provocam externalidades como pressão sobre recursos hídricos e conflitos fundiários. A sustentabilidade econômica, social e ambiental e o capital social são pilares teóricos para analisar a integração entre empresas e comunidades. Nesse contexto, a Responsabilidade Social Empresarial (RSE) é fundamental, buscando mitigar impactos negativos e ampliar o valor compartilhado por meio de práticas sustentáveis e engajamento comunitário. Contudo, estudos apontam que, embora o setor aumente emprego e renda, há lacunas na promoção de melhorias sociais mais amplas, como em educação e saúde. Este estudo investigou as relações macrossociais das usinas paulistas, com foco na percepção dos gestores estratégicos. Utilizou-se a lógica fuzzy para modelar a incerteza e imprecisão dos julgamentos humanos em fenômenos sociais complexos. Foram analisadas quatro variáveis de entrada relacionadas à RSE: Relacionamento com ONGs (ONG), Ações afirmativas em parceria com órgãos governamentais, sindicatos e associações (GSA), Preocupação com relações de trabalho na cadeia produtiva (RTCP) e Existência de estrutura formal no relacionamento interno e externo (ERT). Os resultados mostraram impacto limitado das variáveis na elevação da RSE, especialmente nas interações GSA-ONG e ERT-ONG, percebidas como menos críticas. Entretanto, incrementos em ERT combinados com GSA resultaram em aumento mais substancial, indicando que a formalização das relações de trabalho, aliada a parcerias, pode ser mais eficaz. As combinações envolvendo RTCP apresentaram comportamento intermediário. Conclui-se que a percepção dos gestores sobre a efetividade das variáveis para a RSE no eixo Macrossocial e de Integração (MSI) é pouco significativa, sugerindo a influência de fatores externos não captados pelo modelo. Limitações incluem a restrição à perspectiva dos gestores e a amostragem por acessibilidade, apontando para futuras pesquisas com comunidades, ONGs e poder público.

PALAVRAS CHAVE: Setor Sucroenergético, Responsabilidade Social Empresarial (RSE), Lógica Fuzzy, Desenvolvimento Sustentável, Relações Macrossociais.

ABSTRACT: The Brazilian sugar-energy sector, concentrated in São Paulo, is strategic, with historical roots and continuous technological evolution. Mills play a central role in regional development, generating employment and income, but also cause externalities such as pressure on water resources and land conflicts. Economic, social, and environmental sustainability, along with social capital, are theoretical pillars for analyzing the integration between companies and communities. In this context, Corporate Social Responsibility (CSR) is fundamental,

seeking to mitigate negative impacts and expand shared value through sustainable practices and community engagement. However, studies indicate that although the sector increases employment and income, there are gaps in promoting broader social improvements, such as in education and health. This study investigated the macro-social relations of sugar-energy mills in São Paulo, focusing on the perception of strategic managers. Fuzzy logic was used to model the uncertainty and imprecision of human judgments in complex social phenomena. Four input variables related to CSR were analyzed: Relationship with NGOs (ONG), Affirmative actions in partnership with government agencies, unions, and associations (GSA), Concern with labor relations along the production chain (RTCP), and Existence of a formal structure in internal and external labor relations (ERT). The results showed limited impact of the variables on CSR enhancement, especially in GSA-ONG and ERT-ONG interactions, perceived as less critical. However, increases in ERT combined with GSA led to more substantial growth, indicating that formalization of labor relations, together with partnerships, may be more effective. Combinations involving RTCP showed intermediate behavior. It is concluded that managers' perception of the effectiveness of the variables for CSR in the Macrosocial and Integration (MSI) axis is largely insignificant, suggesting the influence of external factors not captured by the model. Limitations include restriction to managers' perspectives and convenience sampling, pointing to the need for future research involving communities, NGOs, and public authorities.

KEY WORDS: Sugarcane and Energy Sector, Corporate Social Responsibility (CSR), Fuzzy Logic, Sustainable Development, Macrosocial Relations.



1. INTRODUCTION

The Brazilian sugarcane and energy sector represents one of the most solid and strategic production chains in national agribusiness, possessing deep historical roots and a continuous history of technological and organizational evolution. According to data from the Sugarcane Industry Union (UNICA, 2023), the state of São Paulo has consolidated itself as the epicenter of this activity, accounting alone for more than half of the national production of sugarcane, sugar, and ethanol, concentrating large industrial parks and high-complexity logistical operations. This massive presence configures a unique socioeconomic scenario, where mills transcend their strict role as production units to become central agents in modeling regional development, profoundly influencing the population dynamics, infrastructure, economy, and social structure of the municipalities where they are installed.

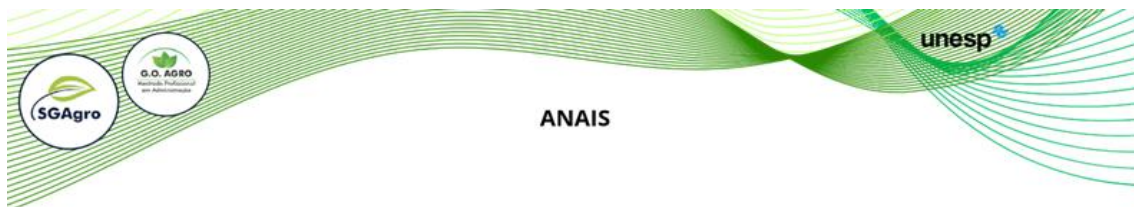
In this context, the analysis of the macrosocial integration and interaction relationships of these companies with their immediate geographic surroundings emerges as a crucial and multifaceted field of study. These relationships operate in a complex duality: on the one hand, the mills function as powerful vectors of development, generating employment, income, tax collection, and fostering local supplier chains (RIBEIRO, 2018). On the other hand, their operation imposes significant externalities, such as pressure on water resources, landscape alteration, labor seasonality, and potential land conflicts, creating a mosaic of impacts that demand strategic and responsible management (ALVES, 2009).

The theoretical relevance of this topic is anchored in discussions about sustainable development and social capital. For classical authors like Sachs, (1993), truly sustainable development rests on three inseparable pillars: economic, social, and environmental, which need to be in harmonious integration between the company and the community.

Complementarily, the theory of social capital, developed by Putnam, (2000), offers a valuable lens to analyze how networking, trust, and norms of reciprocity between the company and its local stakeholders can catalyze or obstruct endogenous development. The "social license to operate," a concept widely discussed in management literature, ceases to be a metaphor and becomes a tangible asset, built through the quality of these macrosocial interactions (LICHTENTHALER, 2017).

Methodologically, fuzzy logic Zadeh, (1965) is chosen, an advanced instrument of applied mathematics and decision sciences. This choice is justified by the tool's capacity to model the uncertainty and imprecision inherent in human judgments and complex social phenomena. Unlike traditional Boolean logic (true/false), fuzzy logic operates with degrees of membership, allowing a variable to belong to more than one set simultaneously and in different intensities (MANNARELLI FILHO, 2023). This is particularly suitable for translating qualitative perceptions (e.g., "high degree of integration," "moderate impact") into data amenable to sophisticated quantitative treatment, through the construction of fuzzy sets and inference systems, offering a more nuanced and realistic view of the object of study.

The central problem addressed by this article resides, therefore, in the complexity of apprehending and analyzing this multidimensionality. How are the macrosocial relations of São Paulo's sugarcane mills configured in practice? Which economic dimensions (generation of employment and income, supplier development), social dimensions (investment in education, health, culture, relations with social movements), and environmental dimensions (water resource management, conservation, pollution) are perceived by managers as most critical or prominent? Despite the recognized importance of the topic, a robust, comprehensive gap persists that captures the perception of the main internal actors about this phenomenon, which is often analyzed only through external quantitative indicators or from the community's perspective.



To overcome this gap, the main objective of this article is to investigate, comprehensively and systematically, the multidimensional aspects that characterize the macrosocial relations of sugarcane mills in the state of São Paulo with the geographic surroundings in which they are installed, capturing and modeling the perception of the strategic managers responsible for these interfaces.

Thus, this study seeks to offer three main contributions: (i) for the academic field, it advances the discussion on stakeholder management and regional development in agribusiness, proposing an innovative theoretical-methodological integration; (ii) for sector managers, it provides a detailed diagnosis that can subsidize the formulation of community relationship strategies that are more effective and aligned with the concept of sustainability; and (iii) for public policy makers, it offers insights that can guide the creation of regulatory frameworks and incentives that foster a more positive and productive integration between the sugarcane sector and São Paulo society.

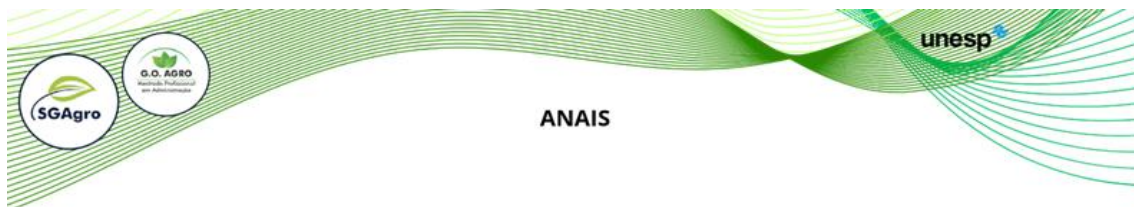
2. THEORETICAL FRAMEWORK

The sugar and alcohol sector constituted one of the primary foundations of the Brazilian colonial economy. Distinguished by sugar production, which supplied the domestic market and consolidated itself as the country's main export commodity over centuries, this sector fostered the development of several regions, notably on the coast, where edaphoclimatic conditions were favorable. The growing demand for sugar resulted in the expansion of the agricultural frontier and the incorporation of more sophisticated productive techniques, thus conforming the economic and social base of the time (SZMERECSÁNYI, 1979; MANNARELLI FILHO, GABRIEL FILHO and BAPTISTA, 2024)

In the 1960s, the Brazilian sugar and alcohol sector was characterized by a significant influx of investments that, however, was not accompanied by a proportional growth in demand, both domestic and international. This imbalance between supply and demand resulted in a scenario of sugar overproduction, which, in turn, exerted downward pressure on world market prices, triggering a severe sectoral crisis between 1973 and 1974. Simultaneously, the international context was marked by the 1973 oil crisis, a geopolitical event that caused an abrupt jump in barrel prices, raising it from approximately US\$ 3 to US\$ 18 in a short interval of time. The conjunction of this global energy crisis with the internal crisis of overproduction in the sugarcane sector created a critical economic environment for the country (SZMERECSÁNYI, 1989; GUEDES, VIAN, *et al.*, 2013; CERDAS VEGA, 2023).

Subsidized investments were determining factors for the creation and consolidation of the sugar industry, notably in the interior of the state of São Paulo. Despite the concerns of several authors about the socio-environmental impacts inherent in its rapid expansion, a new sugarcane agro-industrial frontier was established. This frontier not only consolidated itself but also surpassed the traditional producing region of the Brazilian Northeast in terms of national prominence. Data from the Sugarcane Agribusiness Union (UNICA) referring to the 2022/23 harvest attest to this hegemony: the state of São Paulo alone accounted for 314,508,678 tons of crushed cane, equivalent to 51.78% of the national production, totaling 607,413,483 tons (UNICA, 2023).

Beyond generating wealth for owners, the sugarcane agribusiness exerted profound influence on social relations, being intrinsically associated with the plantation system, whose base was enslaved labor. Over time, the sector underwent significant transformations, adapting to new market demands and diversifying its production, notably with the incorporation of ethanol manufacturing. In contemporary times, the sugarcane agribusiness remains a fundamental pillar of the Brazilian economy, demonstrating not only its perennial historical



relevance but also a modern role in promoting the country's economic and environmental sustainability (EPIFÂNIO, 2023).

The sugarcane and energy sector constitutes a fundamental pillar of the national economy, in which Corporate Social Responsibility (CSR) assumes growing strategic relevance. The production of sugar, ethanol, and bioelectricity not only generates wealth and drives economic development but also opens space for the consolidation of CSR practices. Through the adoption of sustainable operations, investments in surrounding communities, education and health programs for employees and their families, and the rigorous observance of ethical labor standards, companies in the sector can significantly broaden their socio-environmental contribution. The strategic integration of companies with their geographic surroundings is especially critical, which includes the development of local production chains, constant dialogue with regional stakeholders, and the valuation of local culture and ecosystems. This territorial action not only mitigates negative impacts but also potentiates shared value, demonstrating an authentic and structural commitment to corporate social responsibility (MANNARELLI FILHO, 2023).

The internalization of the Sustainable Development Goals (SDGs), proposed by the United Nations (UN) 2030 Agenda, consolidates itself as a differentiating strategic vector for the business sector; this commitment transcends mere rhetoric, materializing through the systemic integration of these objectives into corporate and operational strategies. The achievement of this alignment is fundamentally dependent on the constant adoption of good management practices and the promotion of sustainability-oriented innovations, which constitute the basis for substantive and measurable corporate engagement with the global development agenda (LORETO, AZEVEDO and MARIANO, 2018).

The relevance of Corporate Social Responsibility (CSR) must be understood as a phenomenon of a humanist nature, intrinsically integrated into the corporate sphere, and not as an isolated initiative. It is configured, in this way, as an innovative managerial approach, grounded in an ethical and sustainable commitment to society. From this perspective, all organizations are required to generate positive impacts in the three dimensions of CSR: social, environmental, and economic. In the particular context of agro-industries in the sugarcane and energy sector, categorized as "transformation industries," the magnitude of their impacts in these three spheres is notoriously significant and demands critical analysis (LUPPI, 2007) (NEVES and DE BENEDICTO, 2022).

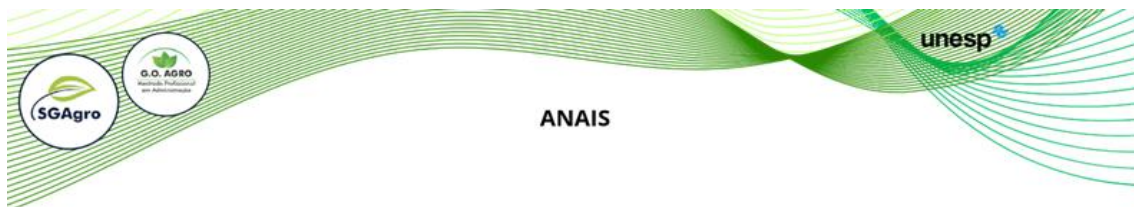
The company-community relationship and the management of externalities are crucial aspects of macrosocial integration. The presence of mills in certain localities generates both benefits and challenges for neighboring communities. In addition to socioeconomic impacts, there are environmental externalities (such as air and water pollution, and deforestation) and social externalities (such as pressure on public services and worker migration) that need to be managed. The literature has explored the dynamics of this interaction, seeking to understand how mills relate to their local stakeholders and what strategies are adopted to mitigate negative impacts and promote sustainable development. The perception of the external public about CSR actions is an indication of the complexity of this relationship and the need for continuous and transparent dialogue between the mills and the communities (RASERA, CORRÊA, *et al.*, 2012).

One of the most prominent debates in the literature concerns the relationship between the economic benefits generated by the expansion of the sugarcane and energy sector and the promotion of broader social development. On the one hand, studies such as that by Bacchi and Caldarelli, (2015), clearly demonstrate that the expansion of the sector is associated with a significant increase in employment and income in São Paulo municipalities. This is a strong

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argument in favor of the sector as a vector of regional economic development, contributing to the improvement of the population's living conditions through the generation of job opportunities and the increase in family income.

Conversely, the same study by Bacchi and Caldarelli, (2015) points to a critical gap: the absence of evidence of an expressive impact of the sector's expansion on broader social indicators, such as education and health. This finding raises the question of whether the economic growth driven by the sugarcane and energy sector is, by itself, sufficient to ensure balanced and equitable social development. The debate lies in the perception that, although the sector contributes to GDP and job creation, its benefits may not automatically translate into improvements in all spheres of human well-being. This suggests that mere economic expansion may not be synonymous with integral social development, demanding the implementation of complementary public policies and corporate actions aimed at improving education and health indicators in the affected communities.

The literature review on macrosocial integration and the interaction of sugar and alcohol mills in the state of São Paulo reveals a dynamic and multifaceted field of research. The analyzed studies demonstrate that the sugarcane and energy sector exerts a significant influence on regional development, with notable impacts on the generation of employment and income. However, the in-depth analysis of the literature also exposes gaps and challenges, particularly regarding the translation of economic benefits into comprehensive improvements in social indicators, such as education and health.

An evolution is observed in the approach to Corporate Social Responsibility (CSR), which transitions from a perspective more focused on legal compliance to a growing concern with the perception of the external public and the proactive mitigation of negative externalities. This movement reflects greater awareness of the complexity of the relationships between mills and surrounding communities, and the need for more transparent and effective engagement.

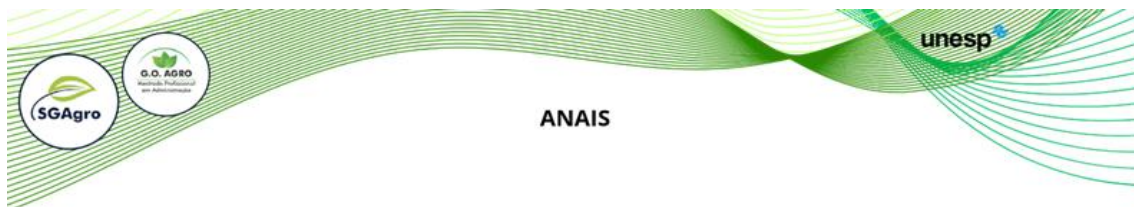
The debates identified in the literature, such as the dichotomy between economic benefits and comprehensive social development, and the tension between legal compliance and proactive engagement in CSR, underline the intricate nature of macrosocial integration. These discussions not only enrich the understanding of the topic but also indicate the need for future research that thoroughly explores the interconnections between economic, social, and environmental aspects, seeking development models that ensure more equitable and sustainable growth for sugarcane-producing regions.

The revised literature offers a solid basis for understanding the macrosocial dynamics of the São Paulo sugarcane and energy sector, while also pointing to the continuous need for deepening and innovative approaches to face challenges and maximize benefits for all interested parties.

3. METHODOLOGY

Qualitative research comprises a broad spectrum of methods and analytical approaches, which seek to incorporate the different dimensions and perspectives of the participants involved. As a predominantly inductive approach, this research modality is not subordinate to predefined hypotheses; rather, it is guided by empirical data and evidence, which constitute the basis for confirming or contesting initial conjectures (GODOY, 1995).

Content analysis is configured as a flexible interpretation methodology, whose application varies according to the theoretical foundation adopted and the specific purposes of the investigation. This approach may include, on the one hand, the use of concepts linked to the statistical semantics of discourse and, on the other, the realization of inferences through the systematic identification of characteristic traits of the messages. The careful execution of this



method proves, therefore, essential to resolve ambiguities, confer analytical rigor, and elucidate the proposed research problems (BARDIN, 2011).

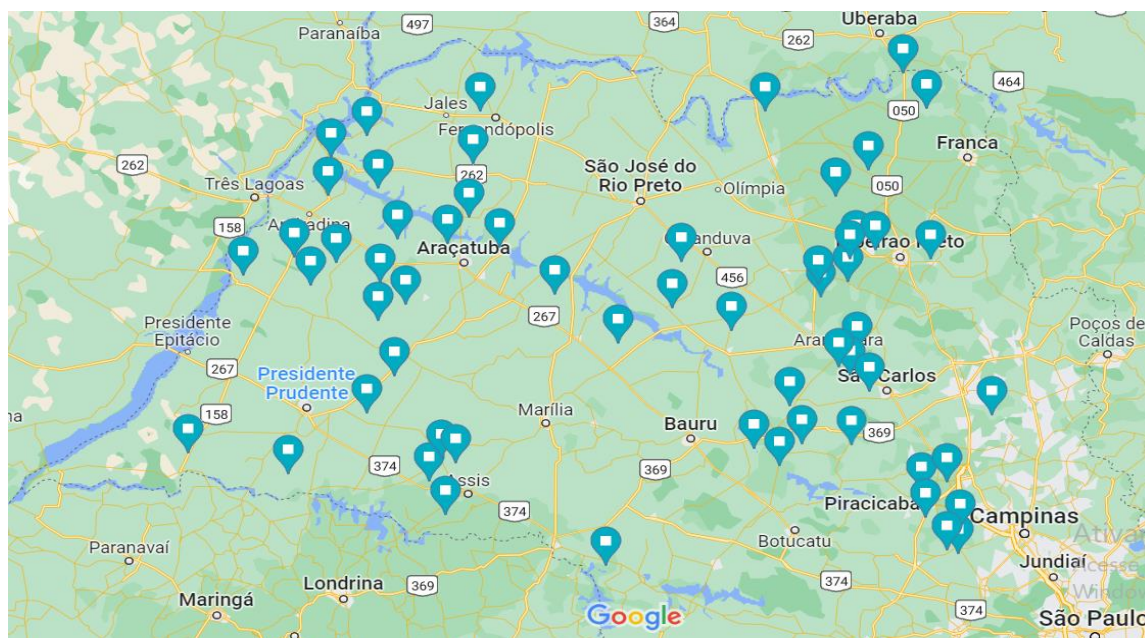
This study adopted content analysis as a methodological procedure, operationalized through a mathematical model based on fuzzy logic. This methodological choice enables a notably more flexible and comprehensive interpretation of the data, given that fuzzy logic is specifically designed to deal with uncertainty, imprecision, and attributes intrinsic to many social research contexts. The integration of this approach allows capturing nuances and gradations of discourses that frequently escape conventional binary analyses, thus providing a richer and dimensional understanding of the phenomenon under investigation.

Complementarily, the adoption of a qualitative-quantitative perspective allowed the combination of qualitative and quantitative data, enriching the analysis and enabling a more robust triangulation of information, an integration particularly valuable for exploring the complexity of human behaviors and opinions, offering a holistic view of the object of study. The study included companies in the sugarcane and energy sector in the state of São Paulo with crushing capacity exceeding 500 thousand tons per harvest, a criterion justified by the sectoral understanding that companies below this volume have reduced relevance and are almost nonexistent in the region, thus concentrating the analysis on the actors with the greatest economic and operational impact.

Data were collected through the application of a questionnaire, available in person and electronically through the Google Forms® platform. The instrument consisted of 15 questions, organized into four thematic categories aligned with the research objectives, with responses structured on a 1 to 5 Likert scale. Before collection, a panel of specialists composed of three professionals with direct experience in the sugarcane and energy sector was formed, with the purpose of establishing the fuzzy parameters necessary for measuring labor relations within the scope of macrosocial and integrating the studied companies.

Data collection was conducted in companies in the sector selected by accessibility and convenience, criteria that, nonetheless, ensured the representativeness of the sample in the state of São Paulo. The questionnaires, structured in 15 questions, were administered under two modalities: in-person and remote. There was no formal request for authorization from the companies to disclose the results, the methodology chosen was to keep all respondents and their respective companies anonymous; however, all respondents' names and their respective companies' names were formally recorded. This ensures that the collected data maintains its integrity for analysis purposes. The geographical distribution of the sampled productive units is presented in Figure 1.

FIGURE 1: Map of the surveyed mills in the state of São Paulo, in the fuzzy questionnaire sample.



Source: elaborated by the authors, based on the Google Maps image, 05/25/23.

The sample selected by convenience for this study comprises 63 companies, corresponding to 36.63% of the total of 172 active productive units in the state of São Paulo. In the 2021/2022 harvest, this set of companies processed 164,023,937 tons of sugarcane, representing 55.03% of the total state crushing. Such a sample cut demonstrates expressive statistical representativeness, as it encompasses undertakings responsible for more than half of the total processing capacity of the state, lending robustness to the data analysis.

Fuzzy models are a valuable analytical tool for decision-making, allowing the systematic integration of qualitative and quantitative data. This approach represents a significant innovation in the classification processes of multidimensional variables in the business environment. By operationalizing value judgments and imprecision inherent in complex contexts, such models facilitate the construction of consensus in situations of conflicting interests, in addition to providing technical subsidies for the strategic allocation of resources in Corporate Social Responsibility (CSR) actions (POPLAWSKA, LABIB, *et al.*, 2015; MANNARELLI FILHO, 2023).

Scholars affirm that the participation of a human specialist, previously interviewed and possessing deep knowledge about the studied phenomenon, is a fundamental step for the robust creation of the fuzzy rule set. This specialist, acting as a source of heuristic knowledge, is responsible for establishing and calibrating the causal relationships between the input variables and the linguistic outputs, defining the degrees of membership and the behavior of the fuzzy sets.

This dependence on specialized judgment gives the system the singular capacity to generate complex and non-linear estimates, mimicking human reasoning even in the face of incomplete or imprecise data, without the need to rely on traditional parametric mathematical models. In this way, fuzzy logic consolidates itself as an autonomous and effective method for

the evaluation of systems in which the relationships between inputs and outputs are ambiguous, complex, or difficult to capture through conventional modeling.

According to Santos, (2008) and Martínez, Cremasco, *et al.*, (2020), fuzzy logic operates through fuzzy sets, which admit continuous degrees of membership, contrasting with the strictly binary nature of classical sets. Its functioning is structured in four sequential stages: fuzzification, which converts precise numerical data into linguistic values; the rule base, which establishes inferential relationships between input and output variables; the inference module, responsible for combining the rules with the fuzzy input data; and, finally, defuzzification, which transforms the fuzzy result into an interpretable numerical value. This systematic framework enables the formal treatment of uncertainties and imprecision, offering a modeling more adherent to the complexity of non-deterministic phenomena.

4. RESULTS AND DISCUSSION OF RESULTS

The data collection instrument, structured in 15 questions, is organized into four central thematic axes, whose detailed arrangement and correspondences can be consulted in Table 2.

TABLE 2: Abbreviations used for the Macrosocial and Integration-MSI sub-axis.

MACROSOCIAL AND INTEGRATION SUB-AXES	ABBREVIATION
Relationship with NGOs in the company's sector: safety, sanitation, housing, education, etc.	ONG
Affirmative actions in partnership with governmental bodies, unions, associations, etc.	GSA
Concern with labor relations up- and downstream of the production chain.	RTCP
Existence of a formal structure in internal and external labor relations.	ERT

Source: elaborated by the authors.

The panel of specialists constituted for the elaboration of the 81 fuzzy rules classified the responses into three linguistic levels, high, medium, and low, operationalized through a Mamdani-type fuzzy controller implemented in Matlab software. The 81 fuzzy rules are calculated considering the 4 input variables and the 3 linguistic levels (high/medium/low), with this combination of 4 variables and 3 linguistic levels representing $3^4 = 81$. The 4 input variables are justified by the complexity of analyzing the problem studied.

This methodological procedure generated three-dimensional response surfaces and corresponding contour maps, which graphically visualize the behavior of the output variables as a function of input combinations. Such representations allow for qualitative and quantitative analysis of the system's sensitivity, clearly demonstrating how variations in the input variables influence and determine the resulting outputs, thus offering an integral view of the modeled non-linear relationships.

The three-dimensional graphs evidence the relationships between three fuzzy variables, enabling the visualization of the response surface through color gradients that represent the distinct degrees of membership of the values in a three-dimensional space. These graphic representations constitute fundamental tools for the understanding of complex systems, as they visually translate non-linear interactions and emergent behaviors that characterize the dynamics of integrated fuzzy variables (KLIR and YUAN, 1995; LAUREANO, COELHO, *et al.*, 2018).

The standard color scale of Matlab® covers a continuous spectrum of shades, ranging from light to dark hues, where the intensity operates as a visual indicator of the degrees of membership: regions with lighter coloring correspond to lower membership values, while areas with darker shades represent high membership values. This chromatic representation facilitates

the immediate identification of membership intensity in different regions of the fuzzy sets. In the present study, the software's standard color palette was adopted without customizations, which is composed of the following colors:

- Red: Fuzzy sets with higher levels of activity and high membership.
- Green: Fuzzy sets with moderate membership and intermediate activity levels.
- Blue: Fuzzy sets with low membership and low activity levels.
- Pink or Purple: Have an undefined situation of fuzzy sets, and are used for sets without clear membership.
- Gray: Indicates a transition zone of fuzzy sets.
- White: Represents empty or null values, where there is no membership.

4.1 THREE-DIMENSIONAL GRAPHS AND CONTOUR MAPS

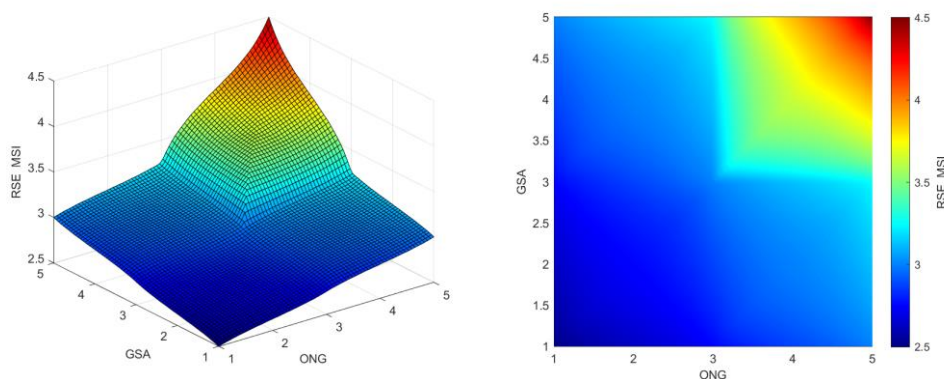
The three-dimensional graphs and contour maps generated by the software always correlate two of the input variables: Relationship with NGOs in the company's sector: safety, sanitation, housing, education, etc. - ONG, Affirmative actions in partnership with governmental bodies, unions, associations, etc. - GSA, Concern with labor relations up- and downstream of the production chain. - RTCP and Existence of a formal structure in internal and external labor relations. - ERT. In the implemented model, the output variable, designated as Corporate Social Responsibility (CSR), is positioned on the Y-axis. It should be noted that the other input variables, associated with Macrosocial and Integration, and not correlated with each other, are kept constant during this specific analysis.

To this end, the Matlab® software assigns these variables a fixed average value of 2.5, thus allowing the isolated visualization of the output variable's behavior in relation to the other inputs under study. Although the questionnaire covers multiple axes, this study focuses only on the MSI axis.

Complementarily, the software generates, for each pair of correlated variables, both a three-dimensional graph and a corresponding contour map. These graphic representations allow users to intuitively visualize the relationships between the input variables and the output variable, facilitating the interpretation of complex scenarios and grounding strategic decisions for the fine adjustment of the system, with a view to optimizing the desired results.

Figure 2 synthetically presents the six graphic arrangements resulting from fuzzy modeling, comprising three-dimensional surfaces and their respective contour maps, which exhaustively illustrate the spectrum of possible correlations between the four variables under analysis.

FIGURE 2: Surface and contour map of the GSA and ONG input variables of CSR

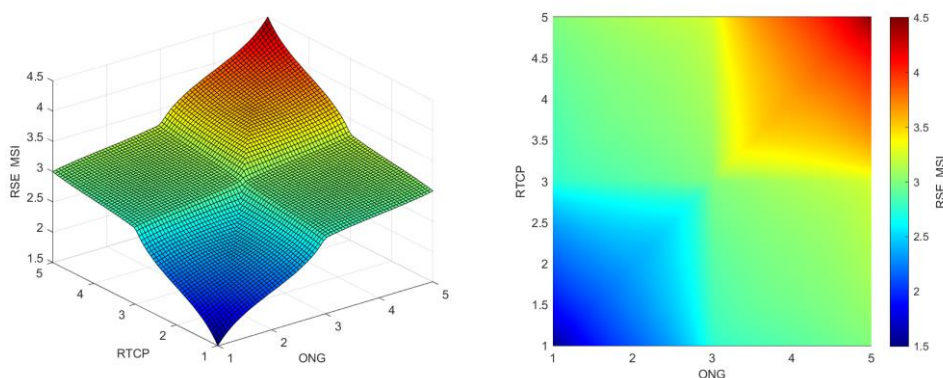


Source: elaborated by the authors.

Figure 2 illustrates the three-dimensional graph and a contour map of the input variables: Affirmative actions in partnership with governmental bodies, unions, associations (GSA), and Relationship with NGOs in the company's sector: safety, sanitation, housing, education (ONG). There is little CSR in the correlation between these two variables, and only for values greater than 4.5 on the Likert scale can an increase in CSR be observed. The blue color is observed, indicating a perception of low CSR for the two variables, and an indication that these ONG and GSA variables are not important for CSR.

It should be noted that the Matlab software can only analyze the combination of two input variables simultaneously; the combination of the input variables ONG and RTCP is presented below in Figure 3.

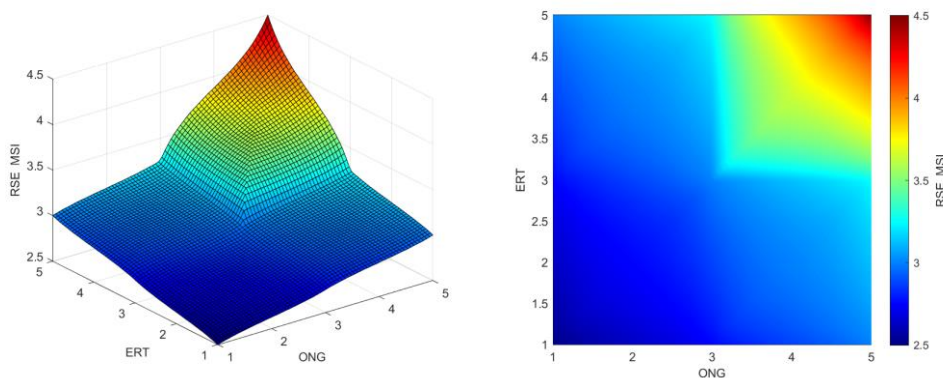
FIGURE 3: Surface and contour map of the ONG and RTCP input variables of CSR



Source: elaborated by the authors.

The Figure above presents considerable equity in the two variables analyzed in relation to the CSR output (Corporate Social Responsibility), with a blue strip indicating low CSR when both variables present values below 3, and high CSR for values above 3 in both variables. It is important to note that there is a well-defined transition for intermediate values, represented by a green coloring that illustrates the gradual nature of the changes in CSR levels in relation to the interactions between the variables.

FIGURE 4: Surface and contour map of the ERT and ONG input variables of CSR



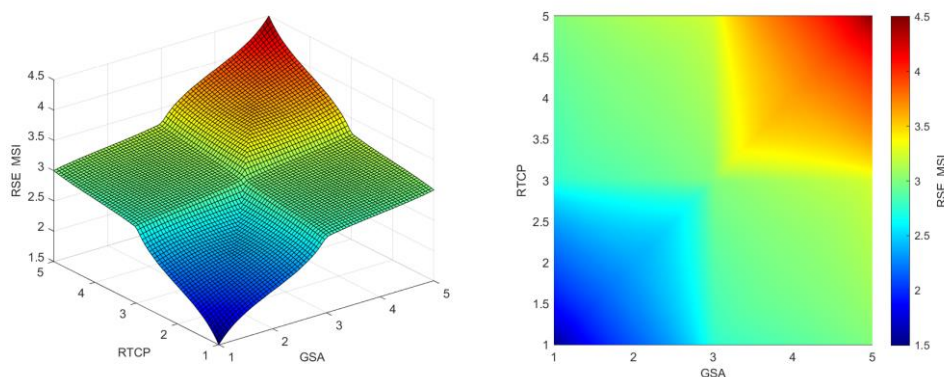
Source: elaborated by the authors.

The graph shows a strong equity relationship between the two analyzed variables and the CSR result. The blue strip indicates low CSR, occurring when both variables are below 3.

As these values increase, CSR also increases, in a transition represented by the green and yellow colors. Values above 4.5 in both variables indicate high CSR, demarcated by the red strip. The transition zone between 3 and 4.5 is clearly delimited.

Figure 5 below presents the contour map of the relationship between the RTCP and GSA input variables.

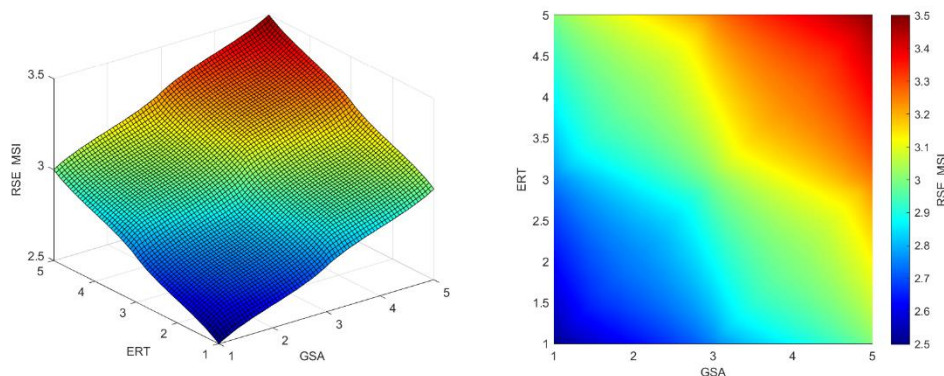
FIGURE 5: Surface and contour map of the RTCP and GSA input variables of CSR



Source: elaborated by the authors.

The Figure evidences an equity relationship between the two input variables and the CSR output. The region of low CSR is defined by the quadrant where the values of both variables are below 3, represented in blue. The quadrant of high CSR is characterized by values above 4.5. The transition zone, understood between 3 and 4.5, is clearly demarcated by a chromatic gradient from green to yellow, corresponding to the intermediate values of the phenomenon.

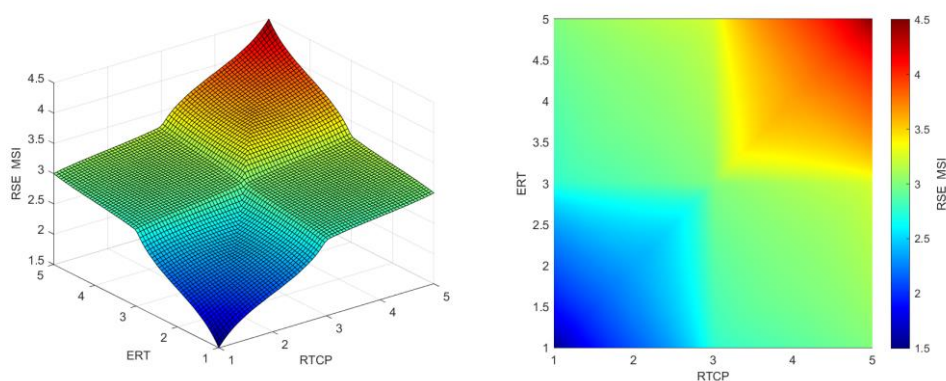
FIGURE 6: Surface and contour map of the ERT and GSA input variables of CSR



Source: elaborated by the authors.

Figure 6 verifies a low correlation with CSR for values up to 3.5 on the Likert scale for the GSA and ERT variables, represented by the dark blue tone. An extensive transition strip, ranging from light blue to green and yellow, corresponds to values between 3.5 and 4.5. The manifestation of high CSR, indicated by the red coloring, occurs exclusively when both variables reach values above 4.5 on the Likert scale.

FIGURE 7: Surface and contour map of the ERT and RTCP input variables of CSR

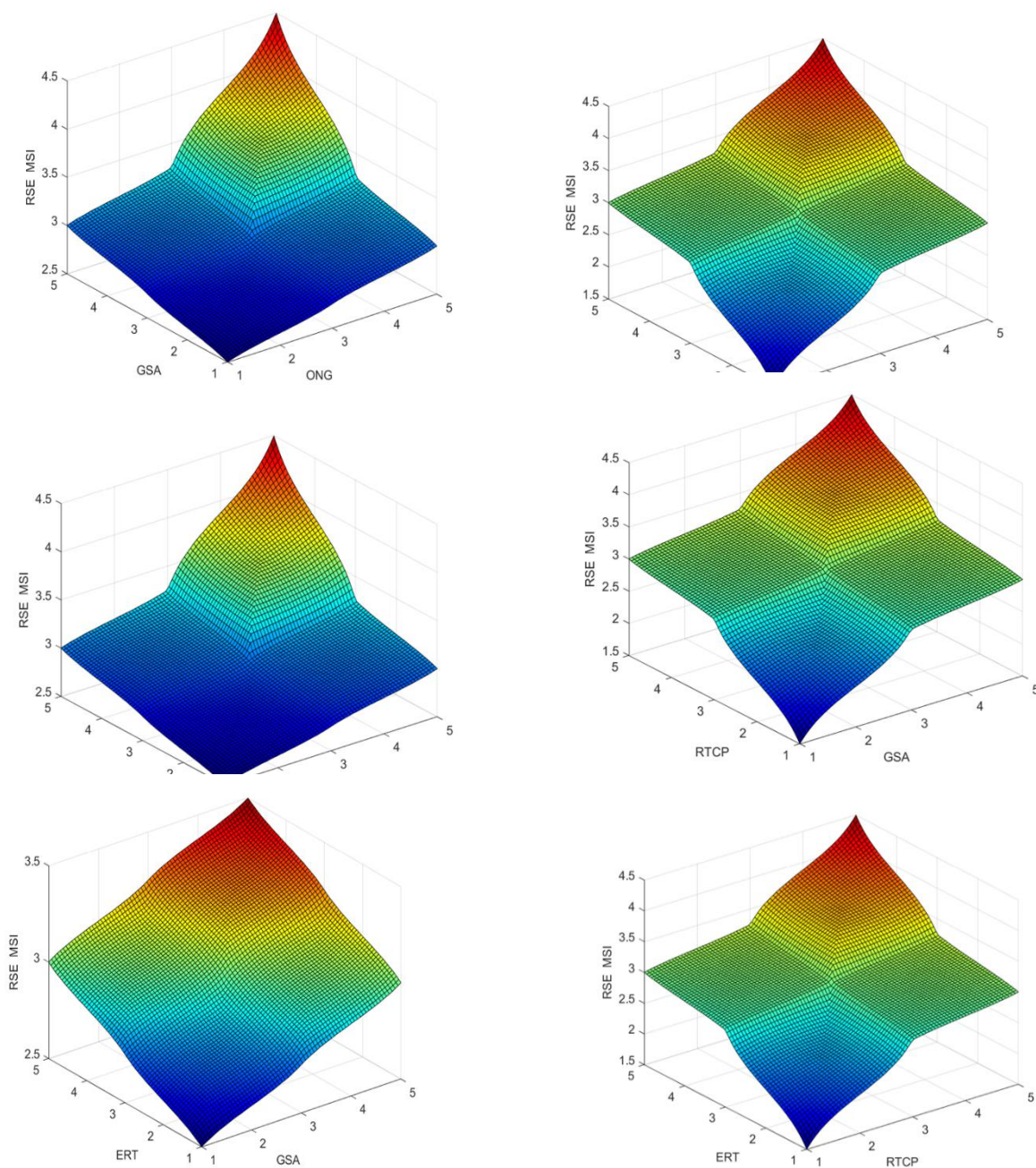


Source: elaborated by the authors.

Figure 7 evidences that the two analyzed variables influence CSR symmetrically. The region of low CSR (in blue) is defined by the quadrant where the values of both variables are less than 3. The quadrant of high CSR is characterized by values above 4.5. The transition strip for intermediate values, understood between 3 and 4.5, is clearly demarcated by a gradient ranging from green to yellow.

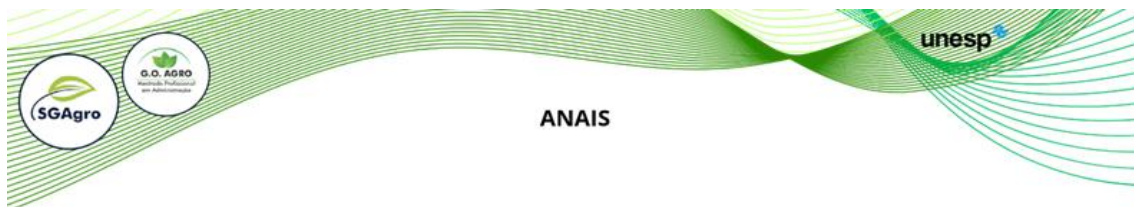
Figure 8 summarizes the results regarding all possible binary combinations between the fuzzy input variables, whose individualized analysis is presented in Figures 2 to 7.

FIGURE 8: Grouped three-dimensional graphs of MSI



Source: elaborated by the authors.

This format of presentation, which incorporates the six combinations of the investigated variables, enables a more detailed analysis of the MSI axis. The three-dimensional graphs,



constructed through fuzzy analyzes performed in the Matlab® software, facilitate a comparative and integral visualization of the relationships.

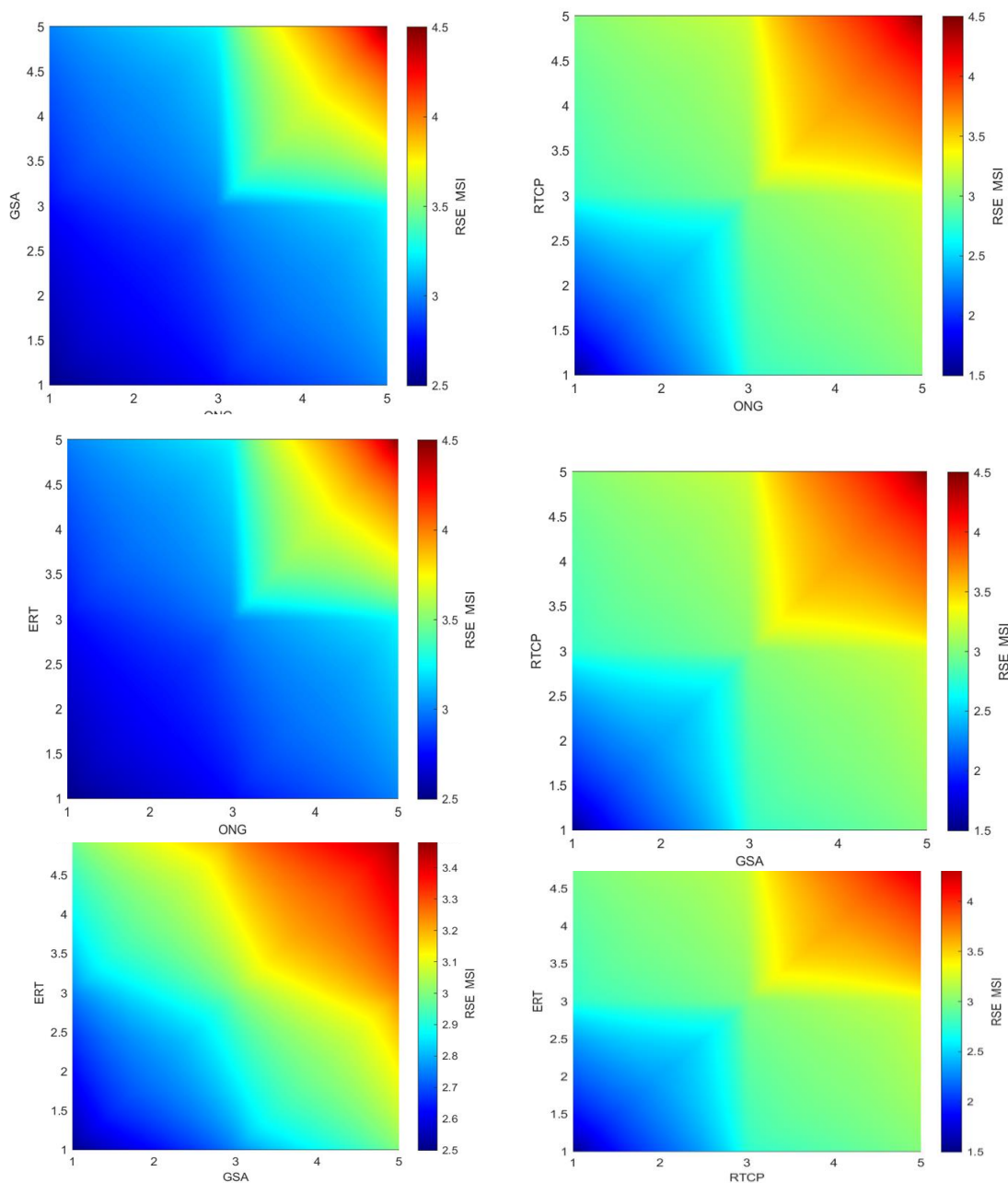
The comparative three-dimensional graphs between the ONG-GSA and ONG-ERT variables present similar behavior patterns. They are characterized by the predominance of the blue region, which denotes low levels of CSR. High CSR, represented by the red color, is observed exclusively when the values of both variables exceed 4.5 on the Likert scale.

Another consistent pattern is observed in three three-dimensional graphs: RTCP vs. GSA, RTCP vs. ONG, and RTCP vs. ERT. These graphs exhibit similar behavior, characterized by low CSR (represented in blue) when values are below 3.0 on the Likert scale. An intermediate CSR strip (green and yellow colors) occurs between 3.0 and 4.0, while high CSR (red) is observed only when values exceed 4.0.

The three-dimensional graph comparing the ERT and GSA variables exhibits a distinct pattern from the others. In this case, low CSR (represented by the blue color) predominates when the values of both variables are below 3.5 on the Likert scale. An intermediate transition strip (green and yellow colors) is observed between 3.5 and 4.0. High CSR (red) occurs exclusively when both variables exceed the value of 4.0.

Figure 9 presents a grouped two-dimensional graphic representation of the six combinations of fuzzy variables, previously illustrated in three dimensions in Figure 8. This complementary visualization assists in the analysis of the MSI axis results.

FIGURE 9: Grouped contour maps of MSI.



Source: elaborated by the authors.

The integrated composition of the two-dimensional contour graphs, which incorporates the six possible combinations between the investigated variables, provides a more granular analysis of the MSI axis. Such graphic representations were generated through computational implementation in the Matlab® environment, using fuzzy logic principles, which allowed a comprehensive and systematic comparative visualization of the results.

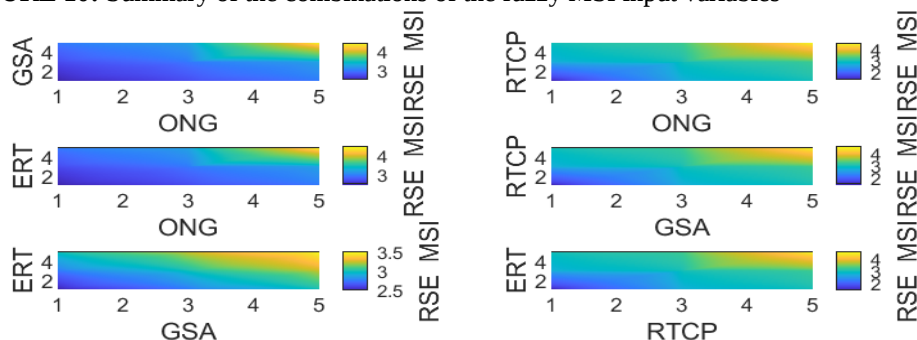
The comparative two-dimensional graphs between the ONG-GSA and ONG-ERT variables exhibit an analogous morphological pattern. In both, the predominance of the blue tone is verified, corresponding to low levels of CSR when the variables present reduced values. The manifestation of high CSR, represented by the red coloring, occurs exclusively when both variables exceed the threshold of 4.5 on the Likert scale.

A distinctive and consistent morphological pattern is observed in three comparative two-dimensional graphs: RTCP-GSA, RTCP-ONG, and RTCP-ERT. Despite the diversity of variables analyzed, all three exhibit convergent behavior, characterized by the presence of low CSR (represented by the blue chromatic dominance) at values less than or equal to 3.0 on the Likert scale. An intermediate transition zone (green-yellow gradient) is also verified for values located between 3.0 and 4.0. The manifestation of high CSR, indicated by the red saturation, occurs exclusively when both variables exceed the level of 4.0.

The two-dimensional contour graph comparing the ERT and GSA variables presents a morphological pattern distinct from the others; the predominance of blue coloring is observed, corresponding to low levels of CSR, when the values of both variables are located up to 3.5 on the Likert scale. An intermediate transition zone, represented by a green-yellow gradient, is verified for values between 3.5 and 4.0. The manifestation of high CSR, indicated by the red saturation, occurs exclusively when both variables exceed the threshold of 4.0.

Complementarily, Figure 10 summarizes the combinations of the fuzzy input variables and their respective output, corresponding to the measurement of CSR in the Macrosocial and Integration (MSI) axis. This representation, generated by the Matlab® software, offers an alternative visualization of the six possible combinations between the four input variables (ONG, GSA, ERT, and RTCP).

FIGURE 10: Summary of the combinations of the fuzzy MSI input variables

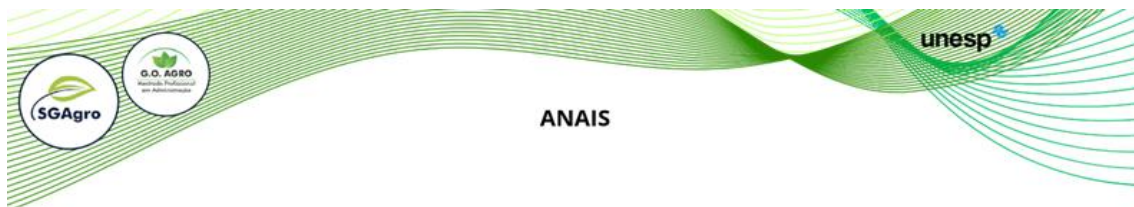


Source: elaborated by the authors.

Figure 10 summarizes the six possible binary combinations between the input variables. In this representation, red saturation indicates greater CSR intensity, while the blue tone corresponds to the lowest values. Intermediate gradients (green-yellow) represent the progressive transition between these extremes.

The analysis reveals that, in most combinations, the input variables do not exert a significant impact on raising CSR. However, a particularity is verified in the interaction between ERT and GSA: in this specific configuration, it is observed that increases in the ERT variable correspond to a more substantial increase in CSR when compared to the other analyzed combinations.

It is further observed that the GSA-ONG and ERT-ONG combinations present the lowest CSR indices, a fact evidenced by the predominance of saturated blue tones in their graphic representation. It is concluded, therefore, that all investigated input variables



demonstrate modest influence as perceived by managers on raising CSR levels in the Macrosocial and Integration (MSI) axis, suggesting the action of exogenous factors not captured by the current model.

5. CONCLUSIONS

The present study aimed to investigate, comprehensively and systematically, the multidimensional aspects that characterize the macrosocial relations of sugarcane mills in the state of São Paulo with their geographic surroundings, capturing and modeling the perception of the strategic managers responsible for these interfaces. To this end, fuzzy logic was employed, an advanced methodological tool capable of dealing with the uncertainty and imprecision inherent in complex social phenomena.

Our findings reveal a nuanced panorama of Corporate Social Responsibility (CSR) in the São Paulo sugarcane and energy sector, according to the perception of managers. The fuzzy modeling of four input variables: Relationship with NGOs (ONG), Affirmative Actions in partnership with governmental bodies, unions, associations (GSA), Concern with labor relations up- and down-stream of the production chain (RTCP), and Existence of a formal structure in internal and external labor relations (ERT), in relation to the output variable CSR, allowed visualizing the interconnections through three-dimensional surfaces and contour maps.

It is notable that, in a large part of the investigated combinations, the input variables demonstrated a limited impact on raising CSR. Specifically, the interactions between GSA and ONG, and ERT and ONG, presented the lowest CSR indices, evidenced by the predominance of blue tones in the graphic representations, suggesting that these aspects are perceived by managers as less critical for global CSR. The perception of low CSR for these variables points to a possible devaluation or ineffectiveness of these strategies in the studied context.

On the other hand, some interactions exhibited distinct patterns. Although most input variables did not demonstrate a significant impact in isolation, it was observed that increases in the ERT variable (Existence of a formal structure in internal and external labor relations) in conjunction with the GSA variable (Affirmative actions in partnership with governmental bodies, unions, associations) corresponded to a more substantial increase in CSR compared to the other combinations. This finding suggests that the formalization and structuring of labor relations, when complemented by affirmative actions and partnerships with governmental bodies and social representations, may be more effective in promoting CSR.

The combinations involving RTCP (Concern with labor relations up- and downstream of the production chain) with the other variables (GSA, ONG, and ERT) showed an intermediate behavior, with a gradual increase in CSR when the values of the variables exceeded 3.0 on the Likert scale, reaching high CSR above 4.0.

The general conclusion is that, although the sugarcane and energy sector is an economic pillar with a crucial role in the country's economic and environmental sustainability, and CSR is of growing strategic relevance, the perception of managers about the effectiveness of the analyzed variables for raising CSR levels in the Macrosocial and Integration (MSI) axis is, for the most part, of modest influence as perceived by managers. Such an observation strongly suggests the action of exogenous factors not captured by the current model, which demands deep reflection on the complexity of company-community relationships and the management of externalities in the sector.

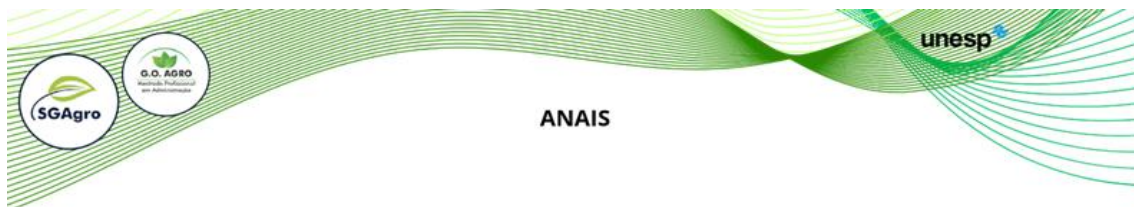
However, the study demonstrates that, in the sugarcane and energy sector of São Paulo, such macrosocial interactions have limited influence, revealing a gap between the perception of managers and effective social development, in connection with the studies of Putnan (2000).

The study presents limitations that affect the generalization and depth of its conclusions. The research was restricted to the perspective of managers of sugarcane mills in São Paulo,

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excluding other relevant actors, such as local communities, NGOs, and governmental bodies, which are essential for a complete understanding of Corporate Social Responsibility (CSR).

Sampling by accessibility, although representative for the São Paulo context, limits the extrapolation of results to other regions or sectors, which may exhibit distinct socioeconomic dynamics and CSR structures.

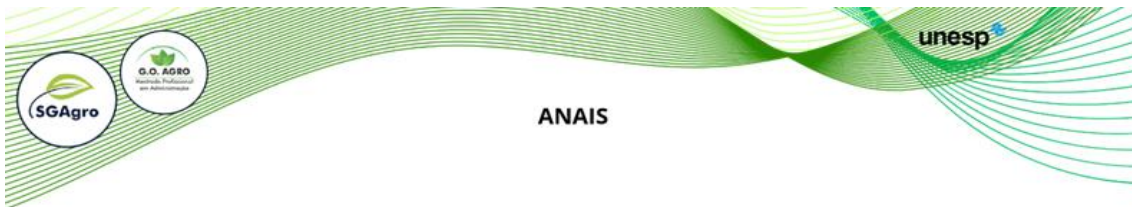
Furthermore, the results indicate that the analyzed variables had a low, non-significant influence on CSR on the Macrosocial and Integration (MSI) axis, suggesting the influence of external factors not accounted for by the model. This finding points to the possible omission of determining variables or the influence of unmeasured elements, underscoring the complexity of company-community relationships and the management of externalities in the sugarcane and energy sector.

The study highlights the need for new research, given the limited impact of the analyzed variables on the CSR levels reported by managers in the sugarcane and energy sector. It is suggested, first, to investigate the perceptions of other actors, such as communities, NGOs, and public authorities, regarding CSR actions to capture a more comprehensive view of macrosocial relations.

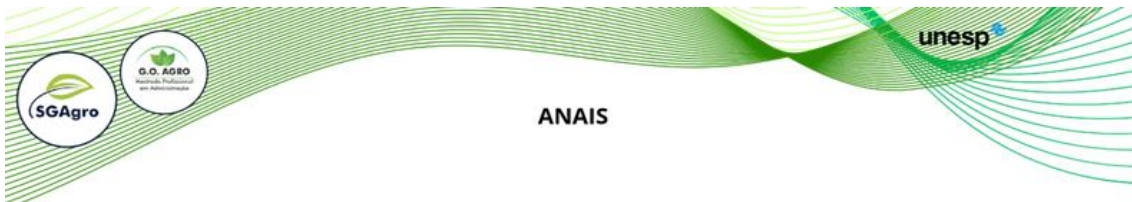
Furthermore, the indication that unmeasured external factors influence CSR opens the way for studies that identify and integrate such variables into future models. Ultimately, the gap between economic benefits and effective social development, particularly in education and health, warrants further investigation. It is necessary to analyze why the sector's growth does not translate into broader social improvements and what public policies or business initiatives could promote a more balanced and sustainable development.

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