POLÍTICA E PRÁTICA NA AGRICULTURA SUSTENTÁVEL: INSIGHTS A PARTIR DE UM MODELO DE ECOEFICIÊNCIA

POLICY AND PRACTICE IN SUSTAINABLE AGRICULTURE: INSIGHTS FROM AN ECO-EFFICIENCY MODEL

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Resumo

O presente estudo avalia a ecoeficiência dos municípios brasileiros com base nos dados do Censo Agropecuário de 2017, concentrando-se em como variáveis institucionais influenciam o desempenho sustentável da agricultura. A ecoeficiência, que equilibra a produção econômica com o impacto ambiental, é estimada pelo método *Slack-Based Measure* e os efeitos de variáveis contextuais são analisados utilizando regressão Tobit. Como principais resultados, educação, associação a cooperativas, financiamento e assistência técnica tem efeito positivo e significativo na ecoeficiência. Destaca-se que um aumento de 1% na associação a cooperativas está correlacionado a um incremento de 0,13% na ecoeficiência, ressaltando o papel fundamental das cooperativas na promoção de práticas sustentáveis. As cooperativas facilitam o acesso a mercados, insumos e conhecimento técnico, melhorando assim os resultados econômicos e ambientais para os pequenos produtores. Esses resultados enfatizam a importância de políticas que apoiem o desenvolvimento cooperativo, a educação rural e o acesso a recursos financeiros e técnicos para fomentar uma agricultura sustentável no Brasil.

Palavras-chave: Slack-Based Measure, Eficiência, DEA, Cooperativa, Educação

Abstract

This study evaluates the eco-efficiency of Brazilian municipalities using data from the 2017 Agricultural Census, focusing on how institutional variables influence sustainable agricultural performance. Eco-efficiency, which balances economic output with environmental impact, is assessed through a Slack-Based Measure approach, and the effects of various contextual factors are analyzed using a Tobit regression. Key findings indicate that education, cooperative membership, financing, and technical assistance significantly enhance eco-efficiency. Notably, a 1% increase in cooperative membership correlates with a 0.13% rise in eco-efficiency, underscoring the pivotal role of cooperatives in promoting sustainable practices. Cooperatives facilitate access to markets, inputs, and technical knowledge, thereby improving both economic and environmental outcomes for smallholders. These results highlight the importance of policies that support cooperative development, rural education, and access to financial and technical resources to foster sustainable agriculture in Brazil.

***Keywords**: Slack-Based Measure, Efficiency, DEA, Cooperative, Education*

1. Introduction

Brazil's agricultural sector plays a vital role in the national economy and commands significant global importance as one of the world's leading producers and exporters of food and raw materials. Understanding its structure and dynamics is essential for crafting effective public policies and fostering sustainable development. The 2017 Agricultural Census conducted by the Brazilian Institute of Geography and Statistics (IBGE) identified a total of 5,073,324 agricultural establishments throughout Brazil. In terms of total land area devoted to agricultural activities, the census recorded 351,289,816 hectares, with a 15,105,125 people workforce. Establishments with 100 ha or less account for 89% of all agricultural establishments and 80% of all workforce. This significant

amount of small agricultural establishments, however, do not translate into financial income, as they represent only 36% of total production revenue.

The total value of agricultural production in 2017 reached BRL 465 billion. Plant production accounted for 66% of this value (R$ 308 billion), with temporary crops contributing the largest share (77%). Animal production accounted for the remaining 34% (R$ 157 billion), with large animals (cattle, buffalo, horses) representing 70% of this value.

While production economic models have shed light on financial performance (Costa *et al.*, 2020; Neves *et al.*, 2019, 2021; Ramos and Vieira Filho, 2023), they often neglect the environmental degradation inherent in Brazil's agricultural expansion. This oversight underscores the need for a broader framework, as economic performance cannot be considered in isolation from environmental sustainability. Brazil's agricultural sector is associated with a wide variety of significant environmental impacts stemming from the expansion of farming and livestock activities, management practices, and input use. The conversion of native vegetation—especially in the Amazon and Cerrado biomes—into cropland or pasture has driven deforestation, accounting for over 97 percent of native vegetation loss in the last six years (MapBiomas, 2025). Inadequate soil management practices—such as continuous monocropping without rotation, conventional tillage, and slash-and-burn clearance—have also led to soil degradation, organic-matter loss, compaction, and erosion (Sambuichi *et al.*, 2012).

Building on these foundational studies, which predominantly concentrate on financial outcomes, the present research adopts a broader perspective by introducing the concept of eco-efficiency—an integrative metric that aligns economic performance with environmental stewardship and directly reflects the dual objectives of financial well-being and environmental sustainability, in line with several United Nations Sustainable Development Goals. From this broader approach, we build the research hypothesis:

- H1 – Membership in cooperatives has a positive impact on eco-efficiency (Neves *et al.*, 2019, 2021; Ramos and Vieira Filho, 2023).

- H2 – Technical assistance has a positive impact on eco-efficiency (Rosano-Peña *et al.*, 2022).
- H3 – Education has a positive impact on eco-efficiency (Ramos and Vieira Filho, 2023; Rosano-Peña *et al.*, 2022).
- H4 – Organic agriculture has a positive impact on eco-efficiency.
- H5 – Financing agriculture establishments have a positive impact on eco-efficiency (Ramos and Vieira Filho, 2023; Rosano-Peña *et al.*, 2022).
- H6 – Municipality location has an impact on eco-efficiency (Neves *et al.*, 2019; Ramos and Vieira Filho, 2023).

The objective of this study is to measure the eco-efficiency of Brazilian municipalities using the 2017 Agricultural Census and to analyse how institutional variables influence that eco-efficiency. In this sense, Slack-Based Measure allows us to quantify eco-efficiency by evaluating both economic (desired) output and environmental externalities (undesired), while Tobit Regression accommodates the censored nature of efficiency scores, enabling robust analysis of contextual variables not in municipalities' control.

2. Literature Review

Eco-efficiency, a core concept in sustainability science, integrates economic performance with environmental stewardship. The Organization for Economic Co-operation and Development defines it as "the efficiency with which ecological resources are used to meet human needs," operationalized as a ratio of economic output (e.g., sales value, value added) to environmental pressure. This aligns with the World Business Council for Sustainable Development (Schmidheiny and Stigson, 2000), which positions eco-efficiency as a tool to "evaluate economic returns relative to environmental impacts" across product lifecycles. Expanding on this, the WBCSD emphasizes its goal of delivering "competitively priced goods and services that improve

quality of life while reducing ecological impacts to align with planetary carrying capacity."

The term's theoretical roots trace to Schaltegger and Sturm (1989), who framed eco-efficiency as "creating more value with less environmental impact". This duality is quantified by Meul *et al.* (2007) as "economic value-added per unit of environmental impact," while Saber *et al.* (2021) simplify it to "net economic profit per unit of environmental damage". From a resource management perspective, eco-efficiency also reflects the capacity to "achieve economic outcomes with minimal resource depletion and environmental degradation" (Gómez-Limón *et al.*, 2012). Suzigan *et al.* (2020) further contextualize it as a sustainability metric that "incorporates environmental costs into efficiency assessments." As such, Data Envelopment Analysis (DEA) methods have been widely used to quantify eco-efficiency (Suzigan *et al.*, 2020).

Rooted in Farrell`s (1957) conceptualization of productive frontiers, DEA measures relative efficiency by comparing decision-making units (DMUs) against an empirical frontier of optimal performance (Charnes *et al.*, 1978). This non-parametric method accommodates multiple inputs and outputs without assuming predefined functional relationships, making it particularly suitable for analyzing heterogeneous agricultural systems (Cooper *et al.*, 2007; Simar and Wilson, 2007). Recent developments, such as Slack-Based Measure (Tone, 2001), further advance the field allowing for undesired externalities as production outcomes.

Building on this methodological foundation, recent empirical research highlights the interconnected role of cooperatives in advancing eco-efficiency. Empirical studies suggest that cooperative structures positively influence eco-efficiency by fostering knowledge-sharing, improving access to sustainable technologies, and enhancing farmers' market bargaining power (Rosano Peña *et al.*, 2018). These benefits are further supported by spatial econometric analyses in Brazil, where cooperatives boosted agricultural output in the Southeast, Center-West, and South regions, though their impact varied geographically (Neves *et al.*, 2019). Beyond environmental benefits, empirical literature has supported that cooperatives contribute to social efficiency by

prioritizing community well-being (Calabrese and Falavigna, 2024; Silva and Morello, 2021). However, the concept of "social eco-efficiency" remains inconsistently defined, with studies often overlooking social indicators in sustainability assessments (Suzigan *et al.*, 2020).

The present study represents a novel perspective in current literature, as it brings an eco-efficiency perspective, directly related to the mutuality seen in cooperative organizations and ONUs ODS. Further, besides cooperativism, we assess the impact of other relevant contextual variables in Brazilian agriculture eco-efficiency, considering different return to scales and treating outliers.

3. Methods and Materials

3.1 Theoretical Framework

Production can be characterized by a given technology, resulting from the incorporation of scientific knowledge into the processes, and represents the main constraint faced by managers in optimizing results. Formally, this technological constraint is the combination and transformation of inputs to produce a given output. Thus, the set of input-output (x, y) combinations, where input x can produce output y, is called the technology set or production set:

$$T = \{(x, y) \mid x \text{ can produce } y\} \quad (1)$$

Each (x, y) combination is a feasible productive process observed empirically or not, and we adopt assumptions on the presented technology set, based on Färe et al. (1989).

Assumption 1: *Weak Essentiality*, where output production is impossible without the use of, at least, one input. $(0, y) \notin T$.

Assumption 2: *Inaction*, where not producing anything is part of the technology set. $(0, 0) \in T$.

Assumption 3: *Convexity*, where the technology set is limited, in the sense that for each input vector, there is a maximum amount of produced output. Convexity can be

defined as if two production processes are feasible, then any mixture of them is also feasible.

Assumption 4: *Free disposability*, where if an (x, y) combination is a feasible production, then any (x', y') where x' is larger and y' smaller is also a feasible production.

Assumption 5: *Constant returns to scale*, where input changes result in a proportionate response in output production.

Assumption 6: *Variable returns to scale*, where changes in inputs do not result in a proportionate response in output production. This can be either increasing or decreasing. One must note that increasing returns to scale invalidate Assumption 3.

The most prominent technique to model T and estimate the efficiency measurements is the Shephard (1953) distance function, which provides a functional representation of the technology set that needs no specific behavioral assumption such as cost minimization or profit maximization. In sum, distance functions measure the proximity of a boundary point to a set in a multidimensional space, indicating the radial reduction (expansion) of inputs (outputs) to project inefficient DMUs at the boundary. DEA and Slack-Based Measure use this ratio to estimate T and measure the technical efficiency of a production unit based on its proximity to the efficient frontier.

3.1.1 Slack-Based Measure

The Slack-Based Measure (SBM), introduced by Tone (2001), is a non-radial Data Envelopment Analysis (DEA) model designed to evaluate the efficiency of decision-making units (DMUs) by directly incorporating input and output slacks into the objective function. Unlike traditional radial DEA models (e.g., CCR or BCC), which assume proportional adjustments to inputs or outputs, the SBM identifies non-proportional inefficiencies by measuring excess inputs (input slacks) and output shortfalls (output slacks). This approach avoids the overestimation of efficiency inherent in radial models and provides a more granular assessment of performance.

In the output-oriented SBM formulation under variable returns to scale (VRS), the model seeks to maximize output expansion while accounting for potential input reductions. Consider *n* DMUs, each consuming *m* inputs ($\boldsymbol{x} \in R_+^m$) to produce *s* desirable outputs ($\boldsymbol{y^g} \in R_+^s$) and *k* undesirable outputs ($\boldsymbol{y^b} \in R_+^k$). Let $X = [x_1, \ldots, x_n], Y^g = [y_1, \ldots, y_n], Y^b = [y_1, \ldots, y_n]$ denote the input, desirable output, and undesirable output matrices, respectively. For a target DMU*o*, the output-oriented SBM efficiency score $\rho*$ is derived by solving the following fractional program:

$$\rho^* = \min_{\boldsymbol{\lambda}, \boldsymbol{s^-}, \boldsymbol{s^{g+}}, \boldsymbol{s^{b-}}} \frac{1 + \frac{1}{s+k}\left(\sum_{r=1}^{s} \frac{s_r^{g+}}{y_{ro}^g} + \sum_{q=1}^{k} \frac{s_q^{b-}}{y_{qo}^b}\right)}{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{io}}} \tag{4}$$

subject to:

$$\begin{aligned} x_o &= X\lambda + s^-, \\ y_o^g &= Y^{g\lambda} - s^{g+}, \\ y_o^b &= Y^{b\lambda} + s^{b-}, \\ \lambda \geq 0, \quad s^-, s^{g+}, s^{b-} &\geq 0, \\ \sum_{j=1}^{n} \lambda_j &= 1 \end{aligned} \tag{5}$$

where λ is the intensity vector, s^- represents input excesses, s^{g+} denotes shortfalls in desirable outputs, and s^{b-} captures excesses in undesirable outputs. The VRS constraint $\sum_{j=1}^{n} \lambda_j = 1$ ensures convex combinations of DMUs, accommodating scale heterogeneity. The efficiency score $\rho* \geq 1$, with $\rho* = 1$ indicating full efficiency (no slacks).

A key advantage of SBM is its ability to natively integrate undesirable outputs into the efficiency calculation. Unlike conventional DEA models, which require ad hoc adjustments (e.g., treating undesirable outputs as inputs or applying monotonicity-reversing transformations), the SBM directly incorporates undesirable outputs as separate variables with dedicated slack terms s^{b-}. This preserves the model's

theoretical coherence and avoids methodological distortions. Computationally, the fractional SBM problem is linearized via the Charnes-Cooper transformation.

3.1.2 Impact of Contextual Variables on Eco-Efficiency

Non-parametric methods for efficiency analysis offer specific methods for incorporating contextual variables, which impact but are beyond the control of decision-makers. These contextual variables reflect factors external to the production process and, therefore, are excluded from single-stage efficiency index modeling. However, they provide important information to understand the impact of external conditions on the performance level. These variables help explain variations in performance that are not directly linked to the unit's management and are introduced later in the investigation, in what is known as second-stage analysis. In this stage, initially presented by Ray (1991) and later developed by other authors, regression methods are used, where the dependent variable is the efficiency index obtained in the first stage and the explanatory variables are the factors (z_j), used as explanatory variables to understand the differences in performance. It is given by:

$$\rho_k^* = \beta_0 + \beta_1 z_{1k} + \beta_2 z_{2k} + \cdots + \beta_n z_{rk} + \varepsilon_k \quad (6)$$

where ρ_k^* is the Debreu-Farrell efficiency of k units, z_k is the vector of r contexual variables, β_r represent the coefficients and ε_k is the random error.

Although ordinary linear regressions are widely used in practice, they suffer from the theoretical problem of not considering efficiencies as values limited in the range (0, 1]. Therefore, one cannot guarantee that the adjusted value, expected value, or average is less than or equal to 1. Tobit regression is often used to address this problem. The Tobit model is a form of limited dependent-variable (or truncated) econometric specification, used when the outcome variable only takes on values within a restricted range that depend on the observed covariates (Çelen, 2013). As such, the ρ^* eco-efficiency scores follows a right-censored at 1 standard Tobit formulation:

$$y_i = \beta_0 + \beta_1 z_{1k} + \beta_2 z_{2k} + \cdots + \beta_n z_{rk} + \varepsilon_k \quad (7)$$

$$y_i = \begin{cases} y_i^* when\ y_i^* < 1 \\ 1\ when\ y_i^* \geq 1 \end{cases} \quad (8)$$

where y_i is the latent variable.

3.2 The Data

To estimate Brazilian municipalities' eco-efficiency, we use three production economics classic inputs: total agricultural area (land), total expenditures (capital), and total number of workers (labour).

Outputs balance economic viability and environmental sustainability: Gross annual revenue (BRL) measures economic output. Biodiversity pressure, an undesirable output. For each municipality *i*, biodiversity pressure is calculated as $y_i = \frac{1}{e^{\mathrm{SHDI}}}$, where the SHDI is defined as $\mathrm{SHDI} = -\sum_{c=1}^{C}(s_{ci} \cdot \ln s_{ci})$, and $s_{ci} = \frac{\mathrm{Area}_{ci}}{\mathrm{Area}_i}$, where s_{ci} represents the proportion of land allocated to crop *c* relative to the municipality's total agricultural area, and *C* is the number of distinct crops cultivated. The resulting biodiversity pressure y_i ranges between 0 and 1. A value of 1 indicates monoculture farming, reflecting maximal biodiversity degradation due to habitat homogenization Lastly, greenhouse gas emissions (million tons CO_2-eq, GWP-AR5) represent climate impact.

Contextual variables capture influencing factors: Z1 (% of establishments associated with cooperatives), Z2 (% of establishments receiving technical assistance), Z3 (% of establishments practicing organic agriculture), Z4 (% of establishments with producers with at least primary education), Z5 (% of establishments with financing access), and geographic controls Z6 (Latitude) and Z7 (Longitude).

The database for this study was collected from the SIDRA system, aggregated at a minimum level of municipality, representing the 2017 Agricultural Census results, with the exception of "emissions", which was downloaded from the Greenhouse Gas Emission and Removal Estimating System (SEEG) website (https://seeg.eco.br/o-que-e-o-seeg, accessed on 18th of may, 2025).

The original set comprises a total of 5.579 municipalities in Brazil. The available data required a specific cleaning process, as non-parametric efficiency methods are quite sensitive to outliers and missing data. The following steps were followed to build the final database:

- Removed all municipalities with less than 10ha of agricultural area.
- Removed all municipalities with missing information on any of the inputs or outputs.
- Apply Wilson's (1993) process to detect outliers in deterministic nonparametric frontier models.

From the said procedure, 187 DMUs were removed. A total of 5,392 municipalities were analyzed. Table 1 presents the summary of the final dataset.

Table 1: Summary of the final dataset (n = 5.392)

Variable	land	capital	labour	revenue	SHDI	emissions	
		Inputs			Outputs		
Min.	18	60,2	15,0	198	19	329,9	
1st Qu.	12.042	8.211,8	947,5	12.448	9.536	19.402,9	
Median	24.833	21.594,6	1.790,0	34.645	12.824	40.132,4	
Mean	62.281	59.386,4	2.738,0	83.785	13.376	100.322,3	
3rd Qu.	57.981	56.833,6	3.478,0	88.682	16.527	90.011,6	
Max.	1.717.354	1.975.980,3	48.246,0	3.248.127	58.427	2.400.279,5	
Variable	**perc_coop**	**perc_tech**	**perc_org**	**education**	**perc_fin**	**lat**	**long**
			Contextual Variables				
Min.	-	-	-	0,0252	0,0016	-172.951	-488.743
1st Qu.	0,0096	0,0821	-	0,1538	0,0829	-22.802	-5.040
Median	0,0551	0,2143	0,0041	0,2347	0,1409	-18.030	-4.505
Mean	0,1618	0,2796	0,0169	0,2639	0,1697	-16.456	-4.262
3rd Qu.	0,2632	0,4372	0,0159	0,3526	0,2222	-8.477	-3.909
Max.	0,9773	0,9933	0,8717	0,9265	0,7545	4.590	-35

4 Results

4.1 Efficiency

Table 2 presents mean and median eco-efficiency and the number of efficient DMUs in each region:

Table 2: Summary of eco-efficiency scores by region

Region	1st. Q	Mean	Median	3st. Q	N. of Efficient DMUs
Centro-oeste	0.255	0.418	0.417	0.564	9
Nordeste	0.078	0.165	0.110	0.195	15
Norte	0.159	0.273	0.249	0.356	4
Sudeste	0.135	0.298	0.256	0.423	24
Sul	0.215	0.337	0.305	0.431	9
Brasil	0.116	0.271	0.224	0.380	61

The overall average (median) of the municipalities is 0.271 (0.224). The regional averages (medians) differ from the national eco-efficiency results, where the Centre-West leads all regions with 0.418 (0.417), followed by the South region 0.337 (0.305), Southeast 0.298 (0.256), North 0.273 (0.249) and Northeast 0.165 (0.110) as the less eco-efficient.

The results show that there are several eco-inefficient behaviours and most municipalities still require considerable effort to optimize financial outcome with environmental sustainability. By analysing the slacks of the resulting model, we are able to present the possible improvements a DMU can implement in its outputs to reach an eco-efficient score, without changing its inputs. For the Northeast region, the one that showed the lowest value of mean eco-efficiency, the slacks indicate that, on average, it is possible to increase the annual revenue by BRL 267,763, while reducing the impact on biodiversity by 65.3% and reduce the GHG emissions by 47.1%. When aggregating all regions, on average, inefficient DMUs can increase its annual revenue by BRL 300,000, while reducing the impact on biodiversity by 54.4% and reduce the GHG emissions by 43.4%.

This analysis, however, can only make sense if all of municipalities are operating within the same playing field. This, however, is not possible due to the impact

of exogenous variables on efficiency. Following, we present the influence of these contextual variables on eco-efficiency through a second-stage tobit regression.

4.2 Impact of Contextual Variables

The resulting t statistics p-value of variables in the second-stage tobit regression are presented in Table 3.

Table 3: Tobit regression results for contextual variables

Coefficients	Estimate	Pr(>|z|)	Marginal Effects
(Intercept)* **	0,06483	< 2e-16	-
perc_coop* **	0,13350	< 2e-16	0,13350
perc_tech* **	0,06346	< 2e-16	0,06346
perc_org	0,04719	0,407	-
education* **	0,35230	< 2e-16	0,35230
perc_fin* **	0,11950	< 2e-16	0,11950
lat	-0,00040	0,313	-
long* **	-0,00001	< 2e-16	-2e-06

*** Significant at 1%

Aligned with hypothesis H1, H2, H3, H5, association to cooperatives, technical assistance, education and financing were significant and presented a positive impact on eco-efficiency.

Ranking these variables by its marginal effects, education has the highest positive effect on eco-efficiency; *ceteris paribus*, a 1 percent increase in the percentage of agricultural producers with at least primary education can increase eco-efficiency by 0,35%. This is confirmed by the technical literature (Gasson, 1998; de Oliveira Fernandes and Pascual, 2015; Ondersteijn *et al.*, 2006), as a farmer's educational background might significantly influence his/hers ability to comprehend the intricate risks and benefits linked to strategic decisions like diversifying their crops or livestock, or conversely, focusing on increased specialization through advanced process management (Ondersteijn *et al.*, 2006). Simply put, rural managers, like any other manager, make better decisions when they are better prepared.

This requires a robust set of public policies to enhance rural education. However, rural education is barely mentioned and, worse, family agriculture is completely omitted in Brazilian's National Curriculum Framework (BNCC) (Cogo and Cardoso, 2023). Our initial proposition emphasizes the necessity of centring Rural Education in public policy discourse. This focus is warranted not solely by its positive influence on sustainable agriculture, but also by its capacity as a transformative agent and an effective mechanism for poverty reduction.

Second from top to bottom, a 1 percent increase in the number of agricultural establishments associated to cooperatives can increase eco-efficiency by 0,13%. Economic literature has vast support for this finding as cooperatives significantly enhance eco-efficiency in agriculture by addressing economic challenges, market fairness, and promoting sustainable practices. Rural producers affiliated with cooperatives gain substantial advantages, as outlined by Neves *et al.* (2019). These include increased vertical integration, reducing costs by increasing bargaining power in input acquisition and economies of scale due to the larger volume of products managed. Furthermore, the dilution of economic risk through joint actions, inherent to cooperative ventures (Sexton, 1986), provides a critical buffer for individual farmers.

Beyond direct member benefits, by entering specific markets, cooperatives can mitigate the adverse effects of concentrated market structures, compelling existing firms to operate under conditions closer to perfect competition (Sexton, 1990). This competitive pressure can indirectly encourage more efficient and potentially more sustainable practices across the sector.

Gong *et al.* (2019) further emphasize the core functions of cooperatives, citing their primary directive: providing essential economic services such as productive organization, product commercialization, information sharing, technical service provision, and facilitated access to banking services. Notably, agricultural cooperatives are recognized as a crucial instrument in combating rural poverty (Deriada, 2005; Organization, 2012; Ramos and Vieira Filho, 2023). In practice, cooperatives

demonstrably increase the income of their members and contribute to their socioeconomic development (Wossen *et al.*, 2017).

As such, cooperativism stands in contrast to the neoliberal individualistic entrepreneurial approach that can lead to "subordinate integration" (Parreiras, 2007) for family farmers (Silva and Nunes, 2022). Under pressure to produce more with lower costs, solely maximizing profits, many small producers have faced bankruptcy and rural exodus (Sabourin, 2017). Conversely, cooperative strategies are highlighted as essential for fostering resilient family agriculture. The United Nations (2017) explicitly recognizes the positive impacts of agricultural cooperation in achieving the Sustainable Development Goals (SDGs), emphasizing "farmer-to-farmer cooperation as essential to the creation of environments conducive to supporting the exchange of experience and knowledge to scale up relevant, cost-effective, traditional and innovative solutions towards achieving the Sustainable Development Goals".

Within this context, we highlight the Cooperative Institutional Agenda, developed by the OCB System, the leading entity responsible for promoting and defending Brazilian cooperativism, as a crucial tool for the sector's advocacy and development. This agenda outlines two key actions within the agricultural sector. The first is to ensure the continuity of programs and financing lines, which resonates with our study's results showing a significant and positive effect of financing on eco-efficiency. The second is to strengthen family agriculture, which accounts for 72% of agricultural establishments associated with cooperatives, aiming for productive inclusion and social progress for small rural enterprises.

The role of cooperatives is further emphasized and solidified by Complementary Law n. 214/2025. Now, Brazilian legislation ensures appropriate treatment of cooperative acts within the new tax regime, guaranteeing legal certainty and competitiveness for the sector, paving the way for even greater representation of cooperativism in the rural sphere.

Technical assistance and financing also shown significantly positive effects on eco-efficiency, where, *ceteris paribus*, a 1 percent in the number of agriculture

establishments with technical assistance can increase eco-efficiency by 0,06%. Similarly, a 1 percent increase in the number of agricultural establishments that received some sort of financing can increase eco-efficiency by 0,12%. We analyse both of these findings together, as they are interconnected. For long, it was widely assumed that unequal land distribution was the primary cause of high-income concentration in Brazil's rural areas. However, recent studies (da Silva e Souza and Gomes, 2018; de Souza *et al.*, 2018) change this perspective, indicating that access to technology is the main driver behind concentrated production and, quite likely, rural poverty. This new understanding highlights the urgent need for well-designed public policies to improve technical assistance and technological access via financing, fostering productivity gains and social inclusion.

5 Final Remarks

In this study, we estimated agricultural eco-efficiency for 5,392 municipalities in Brazil, providing decision support for public policy on possible improvements for inefficient municipalities, taking as reference the best practices in Brazil. Also, as the estimated eco-efficiency scores are affected by contextual variables not in the managers' control, we adopt a tobit regression model to investigate how these exogenous variables impact eco-efficiency. Confirming our hypothesis H1, H2, H3 and H5, association to cooperatives, technical assistance, education and financing were significant and presented a positive impact on eco-efficiency.

Thus, we fill an important gap regarding the evaluation of the environmental economic performance of agriculture in Brazil, considering not only the sector's financial outcome, but also environmental externalities. As future research, we argue that a panel analysis using data from previous agricultural census can be implemented and further analyse the dynamics of eco-efficiency.

References

Calabrese, G.G. and Falavigna, G. (2024), "Do social cooperatives stimulate social change? An

investigation on Italian firms based on DEA-Malmquist approach", *Technological Forecasting and Social Change*, Vol. 199, p. 123016, doi: 10.1016/j.techfore.2023.123016.

Çelen, A. (2013), "Efficiency and productivity (TFP) of the Turkish electricity distribution companies: An application of two-stage (DEA&Tobit) analysis", *Energy Policy*, Elsevier, Vol. 63, pp. 300–310.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978), "Measuring the efficiency of decision making units", *European Journal of Operational Research*, Vol. 2 No. 6, pp. 429–444, doi: 10.1016/0377-2217(78)90138-8.

Cogo, T.P. and Cardoso, J.B. (2023), "Educação do Campo: uma análise crítica sobre a representação da modalidade na BNCC brasileira em tempos de neoliberalismo", *Revista Educación, Política y Sociedad*, Vol. 8 No. 2, pp. 121–155.

Cooper, W.W., Seiford, L.M. and Tone, K. (2007), *Data Envelopment Analysis*, Springer US, New York, NY, doi: 10.1007/978-0-387-45283-8.

Costa, R.A., Vizcaino, C.A.C. and Costa, E.M. (2020), "Participação em cooperativas e eficiência técnica entre agricultores familiares no Brasil", Instituto de Pesquisa Econômica Aplicada (Ipea).

Deriada, A.L. (2005), "Assessment of cooperative movement in a developing country: The Philippine experience", *国際開発研究フォ-ラム*, 名古屋大学, No. 28, pp. 81–101.

Faere, R., Grosskopf, S., Lovell, C.A.K. and Pasurka, C. (1989), "Multilateral Productivity Comparisons When Some Outputs are Undesirable: A Nonparametric Approach", *The Review of Economics and Statistics*, Vol. 71 No. 1, p. 90, doi: 10.2307/1928055.

Farrell, M.J. (1957), "The Measurement of Productive Efficiency", *Journal of the Royal Statistical Society. Series A (General)*, Vol. 120 No. 3, p. 253, doi: 10.2307/2343100.

Gasson, R. (1998), "Educational qualifications of UK farmers: A review", *Journal of Rural Studies*, Elsevier, Vol. 14 No. 4, pp. 487–498.

Gómez-Limón, J.A., Picazo-Tadeo, A.J. and Reig-Martínez, E. (2012), "Eco-efficiency assessment of olive farms in Andalusia", *Land Use Policy*, Elsevier, Vol. 29 No. 2, pp. 395–406.

Gong TianChen [Gong, T., Battese, G.E. and Villano, R.A. (2019), "Family farms plus cooperatives in China: technical efficiency in crop production?"

MapBiomas. (2025), *RAD2024: Relatório Anual Do Desmatamento No Brasil 2024*, São Paulo.

Meul, M., Nevens, F., Reheul, D. and Hofman, G. (2007), "Energy use efficiency of specialised dairy, arable and pig farms in Flanders", *Agriculture, Ecosystems & Environment*, Elsevier, Vol. 119 No. 1–2, pp. 135–144.

Neves, M. de C.R., Castro, L.S. de and Freitas, C.O. de. (2019), "O impacto das cooperativas na produção agropecuária brasileira: uma análise econométrica espacial", *Revista de Economia e Sociologia Rural*, Vol. 57 No. 4, pp. 559–576, doi: 10.1590/1806-9479.2019.187145.

Neves, M. de C.R., Silva, F. de F., Freitas, C.O. de and Braga, M.J. (2021), "The Role of Cooperatives in Brazilian Agricultural Production", *Agriculture*, Vol. 11 No. 10, p. 948, doi: 10.3390/agriculture11100948.

de Oliveira Fernandes, L.A. and Pascual, U. (2015), "Análise da eficiência da agricultura familiar agroecologista", *Revibec: Revista de La Red Iberoamericana de Economia Ecológica*, Vol. 24, pp. 221–233.

Ondersteijn, C.J.M., Giesen, G.W.J. and Huirne, R.B.M. (2006), "Perceived environmental uncertainty in Dutch dairy farming: The effect of external farm context on strategic choice", *Agricultural Systems*, Elsevier, Vol. 88 No. 2–3, pp. 205–226.

Organization, U.N.F. and A. (2012), "Agricultural Co-operatives. Key to Feeding the World", Rome: FAO.

Parreiras, L.E.R. (2007), "Negócios solidários em cadeias produtivas: protagonismo coletivo e desenvolvimento sustentável", Instituto de Pesquisa Econômica Aplicada (Ipea).

Ramos, É.B.T. and Vieira Filho, J.E.R. (2023), "Desenvolvimento regional da agricultura familiar: Cooperativismo e associativismo", *Revista Brasileira de Economia*, SciELO Brasil, Vol. 77, p. e052023.

Ray, S.C. (1991), "Resource-use efficiency in public schools: A study of Connecticut data", *Management Science*, INFORMS, Vol. 37 No. 12, pp. 1620–1628.

Rosano-Peña, C., Silva, J.V.B., Serrano, A.L.M., Vieira Filho, J.E.R. and Kimura, H. (2022), "Eco-Efficiency of Agriculture in the Amazon Biome: Robust Indices and Determinants", *World*, Vol. 3 No. 4, pp. 753–771, doi: 10.3390/world3040042.

Rosano Peña, C., Serrano, A.L.M., de Britto, P.A.P., Franco, V.R., Guarnieri, P. and Thomé, K.M. (2018), "Environmental preservation costs and eco-efficiency in Amazonian

agriculture: Application of hyperbolic distance functions", *Journal of Cleaner Production*, Vol. 197, pp. 699–707, doi: 10.1016/j.jclepro.2018.06.227.

Saber, Z., van Zelm, R., Pirdashti, H., Schipper, A.M., Esmaeili, M., Motevali, A., Nabavi-Pelesaraei, A., *et al.* (2021), "Understanding farm-level differences in environmental impact and eco-efficiency: The case of rice production in Iran", *Sustainable Production and Consumption*, Elsevier, Vol. 27, pp. 1021–1029.

Sabourin, E. (2017), "Origens, evolução e institucionalização da política de agricultura familiar no Brasil.", *Agricultura Familiar Brasilieira: Desafios e Perspectivas de Futuro.*, pp. 265–291.

Sambuichi, R.H.R., Oliveira, M.Â.C. de, Silva, A.P.M. da and Gustavo Luedemann. (2012), *A Sustentabilidade Ambiental Da Agropecuária Brasileira: Impactos, Políticas Públicas e Desafios*, Rio de Janeiro.

Schaltegger, S. and Sturm, A. (1989), *Ökologieinduzierte Entscheidungsprobleme Des Managements: Ansatzpunkte Zur Ausgestaltung von Instrumenten*, Inst. f. Betriebswirtschaft.

Schmidheiny, S. and Stigson, B. (2000), *Eco-Efficiency: Creating More Value with Less Impact*, World Business Council for Sustainable Development.

Sexton, R.J. (1986), "The formation of cooperatives: a game-theoretic approach with implications for cooperative finance, decision making, and stability", *American Journal of Agricultural Economics*, Wiley Online Library, Vol. 68 No. 2, pp. 214–225.

Sexton, R.J. (1990), "Imperfect competition in agricultural markets and the role of cooperatives: A spatial analysis", *American Journal of Agricultural Economics*, Wiley Online Library, Vol. 72 No. 3, pp. 709–720.

Shephard, R.W. (1981), *Cost and Production Functions*, Vol. 194, Springer Berlin Heidelberg, Berlin, Heidelberg, doi: 10.1007/978-3-642-51578-1.

da Silva e Souza, G. and Gomes, E.G. (2018), "A stochastic production frontier analysis of the Brazilian agriculture in the presence of an endogenous covariate", *International Conference on Operations Research and Enterprise Systems*, Springer, pp. 3–14.

Silva, L.F. and Morello, T. (2021), "Is there a trade-off between efficiency and cooperativism? Evidence from Brazilian worker cooperatives", *Journal of Co-Operative Organization and Management*, Elsevier, Vol. 9 No. 2, p. 100136.

Silva, R.M.A. da and Nunes, E.M. (2022), "Agricultura familiar e cooperativismo no Brasil: uma caracterização a partir do Censo Agropecuário de 2017", *Revista de Economia e Sociologia Rural*, SciELO Brasil, Vol. 61 No. 2, p. e252661.

Simar, L. and Wilson, P.W. (2007), "Estimation and inference in two-stage, semi-parametric models of production processes", *Journal of Econometrics*, Vol. 136 No. 1, pp. 31–64, doi: https://doi.org/10.1016/j.jeconom.2005.07.009.

de Souza, P.M., Fornazier, A., da Silva, A.M. and Ponciano, N.J. (2018), "Tecnologia na agricultura brasileira: uma análise das desigualdades regionais para os segmentos familiar e não familiar", *Revista Econômica Do Nordeste*, Vol. 49 No. 3, pp. 147–169.

Suzigan, L.H., Peña, C.R. and Guarnieri, P. (2020), "Eco-efficiency Assessment in Agriculture: A Literature Review Focused on Methods and Indicators", *Journal of Agricultural Science*, Vol. 12 No. 7, p. 118, doi: 10.5539/jas.v12n7p118.

Tone, K. (2001), "A slacks-based measure of efficiency in data envelopment analysis", *European Journal of Operational Research*, Elsevier, Vol. 130 No. 3, pp. 498–509.

Wossen, T., Abdoulaye, T., Alene, A., Haile, M.G., Feleke, S., Olanrewaju, A. and Manyong, V. (2017), "Impacts of extension access and cooperative membership on technology adoption and household welfare", *Journal of Rural Studies*, Vol. 54, pp. 223–233, doi: 10.1016/j.jrurstud.2017.06.022.