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ECO-EFFICIENCY OF BRAZILIAN AGRICULTURE

Oscar TUPY [1]

[1] Doctor of Sciences. Researcher. Embrapa Southeast Livestock

ABSTRACT

Eco-efficiency is defined as the relationship between the production value of a firm, industry, agricultural production system, municipality, state or country and the environmental impact of the inputs it uses in the production process Eco-efficiency has also been defined in the literature as a quantitative management tool to study economic and environmental aspects concurrently. Therefore, measuring the eco-efficiency of production units in Brazil can be important for the formulation of public policies aimed at reducing the emission of greenhouse gases. This work evaluated the eco-efficiency of agriculture in 27 Brazilian states using the Data Envelopment Analysis –DEA technique. Two inputs were considered in the model, first the CO_2e emissions resulting from the enteric fermentation of ruminants and the management of manure, the second input are the emissions resulting from the use of the soil, cultivation of irrigated rice and burning of residues. As output, the production value per state was used. An average eco-efficiency of 77.9% was obtained for the 27 states, with 25.9% of the states 100% eco-efficient. An average eco-efficiency of 77.9% is equivalent to saying that eco-inefficient states are emitting 22.1% more CO_2e, given the production value obtained.

Key words: Eco-efficiency; Brazilian agriculture; CO_2e emissions

INTRODUCTION

Many studies have been conducted analyzing the eco-efficiency of agriculture, among which the most recent are those of (CHEN & JIA, 2017) with regions in China and Rybaczewska and Gierulski (2018) and MACIEL et al. (2018) with European Union countries. Eco-efficiency is defined as the relationship between the production value of a firm, industry, agricultural production system, municipality, state or country and the environmental impact of the inputs it uses in the production process (HUPPES; ISHIKAWA, 2007; CHEN et al., 2013). The higher the numerator of this relationship, the more eco-efficient the production system will be. Eco-efficiency has also been defined in the literature as a quantitative management tool to study economic and environmental aspects concurrently. Therefore, measuring the eco-efficiency of production units in Brazil can be important for the formulation of public policies aimed at reducing the emission of greenhouse gases. According to SEEG - the Climate Observation System of Greenhouse Gas Emissions of the Climate Observatory (2019) the country issued in 2018, 1,939 billion gross tons of greenhouse gases, measured in carbon dioxide equivalent (CO_2e). This total, 44% (845 MT CO_2e) came from changes in land use, mainly from deforestation in the Amazon and the Cerrado. Second place was agriculture, with 25% of emissions (492 Mt CO_2e) followed by the energy sector, which includes all activities that use fossil fuels, with 23% (408 Mt CO_2e). The objective of this work was to measure the ecoefficiency in agricultural production in the Brazilian states in relation to the emission of greenhouse gases (CO_2e). Several indicators have been used to measure eco-efficiency or environmental efficiency, the most typical of which is the Life Cycle Assessment Method - LCA (POESCHL et al., 2012; OLANDER et al., 2012; HAWKINS et al., 2013). Through the LCA, energy and material consumed and waste released in production can be identified. In this way, the impact of inputs and products on the environment in production can be identified (MIETTINEN, HAMALAINEN, 1997; CHEN; JIA, 2017). Based on the LCA method, several environmental performance indices have been proposed (CARVALHO et al., 2014). The environmental performance indicators were defined as analytical tools that allow comparing several production units, thus facilitating environmental management and the definition of public policies for them. In this work, eco-efficiency indicators were be calculated using the DEA Method (Data Envelopment Analysis) developed by Banker et al. (1984) and used by Chen and Jia (2017) to assess the environmental efficiency of regions in China and Rybaczewska and Gierulski (2018) to assess the environmental efficiency of European countries.

MATERIAL AND METHODS

Description of the data

Input and output data for the 27 Brazilian states were obtained from SEEG (2019) and MAPA (2020), respectively. The main sources of CO_2e emissions during the agricultural production process according to SEEG (2019) are the cattle herd, which emits high amounts of methane (CH4), by fermentation in the rumen of the animals, the so-called enteric fermentation, and the management agricultural soils, mainly through the application of nitrogen fertilizers, followed by the management of animal waste, cultivation of irrigated rice (which also emits methane and the burning of residues, such as sugarcane straw. CO_2e emissions, these sources werel be used as a proxy for inputs in the model used to measure eco-efficiency and the value of production by state as a product following the model used by Rybaczewska and Gierulski (2018) to assess the environmental efficiency of European Union countries Emissions were divided into emissions of animal origin, adding emissions from enteric fermentation and waste management, from now on called input X1, and emissions plant origin, adding the emissions resulting from agricultural soil management, irrigated rice cultivation and burning of residues, hereinafter referred to as input X2. The production value per state was hereinafter called Y1. Emissions were expressed as CO_2 (t) GWP-AR5. GWP (Global warming Potential) obtained from AR5 (fifth IPCC report. CO_2 (t) GWP interferes with the planet's thermal balance.

Model for assessing eco-efficiency

The Mathematical Programming Model - DEA described by Banker et al. (1984) will be used to estimate the eco-efficiency of agriculture in Brazilian states. The model is represented by equation (1) below. Ecoefficiency was assessed from the perspective of inputs. $\text{Min}_{\lambda\theta}, \theta$ subject to $- yi + Y\lambda j \geq 0$, $E\ xi - X\lambda j \geq 0$, $N1'\lambda j = 1$ $\lambda \geq 0$, (1) Where θ is the eco-efficiency indicator for the j-th state; y_i is a vector (m x 1) of the production value (output y1) of state i; x_i is a vector (k x 1) of CO_2e emissions from state i with two types of emissions: enteric fermentation and manure management (input x_1) and management of agricultural soils, residues and aggregate irrigated rice cultivation (input x_2); Y is a matrix (n x m) of production value for all the j-th Brazilian states considered; X is a matrix (n x k) of emissions from the Brazilian j-th states; z_j is a vector (n x 1) of weights that allow us to obtain the optimized eco-efficiency measures generated by mathematical optimization. $N1'\lambda = 1$ is a convexity constraint, N1 being an N x 1 vector of ones. The convexity constraint ($N1'\lambda= 1$) essentially ensures that the inefficient state is compared with others of the same size. The analysis of eco-efficiency conducted from the perspective of inputs determines constant the value of production and measures the excess CO_2e emissions during the production process, indicating for each state relative to the others the reductions in emissions necessary to become efficient.

RESULTS AND DISCUSSIONS

The descriptive statistics of the input product data used to measure eco-efficiency and efficiency measure are shown in Table 1 below.

Table 1. Descriptive statistics of input-product data used to measure the eco-efficiency of Brazilian states in agricultural production.

	Y_1[1]	X_1[2]	X_2[3]	Eco-efficiency[4]
count	27	27	27	27
mean	2,602.5869	2.6851	3.1373	0.7786
standard deviation	2,137.6640	1.0518	2.3499	0.1958
minimum	287.61	1.3216	0.3076	0.39
maximum	8,151.1324	5.4627	11.1544	1

[1] Production value R$/ hectare; [2] Enteric and manure emissions in tonnes / hectare; [3] Emissions from land use and management in tonnes / hectare; and [4] Measure of eco-efficiency in CO_2 emission GWP-AR5 given the value of production.

The average production value per hectare in the states in 2019 was as shown in Table 1 of R$ 2,602, with a minimum of R$ 287 and a maximum of R$ 8,151. The average CO_2e emission resulting from enteric fermentation and waste management was 2.68 tonnes per hectare with a minimum of 1.32 tonnes per hectare and a maximum of 5.46 tonnes per hectare. The average emission resulting from the use of agricultural land, cultivation of irrigated rice and burning of residues was 3.13 tons per hectare with a minimum of 0.30 tons per hectare and a maximum of 11.15 tons per hectare. The average eco-efficiency was 77.86%, that is, on average, the states could have emitted 22.14% less CO_2e than was emitted given the achieved production value. Table 2 shows by state the value of production and the CO_2e emissions observed and the minimum emissions capable of making them eco-efficient given the value of the production presented.

From Table 2 it can be seen, for example, that the state of Acre achieved an ecoefficiency of 40% given the production value, with CO_2e emissions resulting from enteric fermentations and handling of surplus waste of 2.19 tons per hectare and of land use management emissions of 8.66 tonnes per hectare. Explaining the excess emissions by states is outside the scope of this work, requiring detailed specifications of the different aspects of agriculture conducted by each state. However, a positive correlation was estimated ($r = 0.463$) with $p < 0.05$ between the ratio of agricultural area / total area of the state with eco-efficiency. A negative correlation ($r = - 0.511$) with $p < 0.01$, was also estimated between pasture area / total state area with eco-efficiency. The correlation can be explained by the higher CO_2e emission, when the livestock area is dominant in the state, due to the fact that, in these areas, there is generally no integrated crop and livestock forest (ILPF), being the same exploited with extensive livestock with less added value. When the participation of the agricultural area increases in relation to the total area, CO_2e emissions are lower and the eco-efficiency of the state in question increases. The discussions of the results obtained by this work were hampered by the absence of similar studies conducted in Brazil, and in the studies by Chen et al. (1917) and Rybaczewska and Gierulski (2018) there were, respectively, differences regarding the model used and regarding the inputs considered. The 100% eco-efficient states were seven, AP, DF, ES, BA, RR, RN and PR representing 25.9% of the sample and the least eco-efficient and the least eco-efficient (<50%) were AC, RO and AL representing 11.1% of the sample (Table 2).

Table 2. Observed values, target values and excess CO_2 emissions GWP-AR5 in the agricultural production process of the Brazilian states in 2019.

	Observed values			Target inputs		Excess		
States	**Y_1**	**X_1**	**X_2**	**X_1**	**X_2**	**X_1**	**X_2**	**Ecoefficiency**
AC	1,406.99	3.67	11.15	1.48	2.49	2.19	8.66	0.40
AL	2,104.64	4.63	2.07	1.95	0.87	2.68	1.20	0.42
AM	2,498.97	2.33	2.43	1.76	1.49	0.57	0.94	0.75
AP	287.61	1.32	2.76	1.32	2.76	0.00	0.00	1.00
BA	2,035.32	1.59	1.35	1.59	1.35	0.00	0.00	1.00
CE	1,063.69	2.33	1.50	1.66	1.07	0.67	0.43	0.71
DF	6,019.88	3.40	1.77	3.40	1.77	0.00	0.00	1.00
ES	4,250.61	2.39	2.03	2.39	2.03	0.00	0.00	1.00
GO	2,816.27	2.71	3.18	1.87	1.59	0.84	1.59	0.69
MA	1,231.56	2.42	2.67	1.53	1.68	0.89	0.99	0.63
MG	1,813.04	2.05	2.98	1.55	1.75	0.50	1.23	0.76
MS	1,734.76	1.87	3.19	1.54	1.90	0.33	1.30	0.82
MT	3,440.01	2.46	2.31	2.10	1.78	0.36	0.53	0.85
PA	952.16	2.51	4.28	1.42	2.42	1.09	1.86	0.57
PB	934.90	2.29	1.61	1.64	1.15	0.65	0.45	0.72
PE	2,376.73	2.59	1.89	1.80	1.31	0.79	0.58	0.69
PI	1,495.55	1.67	1.30	1.61	1.26	0.05	0.04	0.97
PR	8,151.13	4.42	2.25	4.42	2.25	0.00	0.00	1.00
RJ	1,602.76	2.84	5.19	1.51	2.14	1.33	3.06	0.53
RN	1,205.88	1.86	0.31	1.86	0.31	0.00	0.00	1.00
RO	1,782.42	3.96	9.56	1.55	1.81	2.41	7.75	0.39
RR	800.25	1.37	3.59	1.37	3.59	0.00	0.00	1.00
RS	3,809.46	2.55	3.15	2.23	1.90	0.32	1.25	0.88
SC	7,430.13	5.46	3.86	4.05	2.21	1.42	1.65	0.74
SE	1,361.94	2.13	1.87	1.58	1.39	0.55	0.48	0.74
SP	6,739.70	3.96	2.12	3.73	2.00	0.23	0.12	0.94
TO	923.50	1.72	4.34	1.39	3.37	0.33	0.97	0.81

CONCLUSIONS

Despite the continuous improvement in the productivity of Brazilian agriculture, it carries the challenge of reconciling high productive performance with better environmental performance. This study reveals that only 25.9% of the states are eco-efficient, with the other states needing to align the value of their production with CO_2e emissions. Practices for integrating crop and livestock forestry should be accelerated, including with the rotation of legumes such as soybeans, alfalfa and pigeon pea integrated into eucalyptus reforestation in livestock, legumes can reduce emissions resulting from the use of nitrogen in pastures and in the production of corn and cotton. The massive introduction of forests to pastures can in a short time mitigate methane emissions from the enteric fermentations of ruminants. The DEA technique can be a good tool to support efficient environmental management by identifying eco-efficient and eco-inefficient systems.

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