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RESEARCH ARTICLE

REVISED Frontier model of the environmental inefficiency effects on livestock bioeconomy [version 3; peer review: 3 approved, 1 not approved]

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Abstract

Background

This work was focused on measuring environmental inefficiency in Mexican dairy farms, considering climate change variables related to the emission of greenhouse gases (GHG) and planetary geomagnetic activity.

Methods

The applied methodology measures the eco-efficiency of Mexican dairy farms using the empirical application of a stochastic frontier model of the bioeconomy. The productive sector of the bioeconomy studied was the eco-intensification of the livestock production system (dairies). The environmental inefficiency effect was assumed to be a distribution-independent truncation of a normal distribution with constant variance, while the mean was a linear environmental function of the observable variable.

Results

The results showed that the coefficients of the frontier model were highly significant, highlighting the investment in livestock (50%). The inefficiency model had an impact on climate variation with greenhouse gas emissions CH4 (1.96%). The results of the environmental technical efficiency in geometric average were 81.28%.

Open Peer Review

Approval Status ✗ ✓ ✓ ✓

	1	2	3	4
version 3 (revision) 18 Jun 2024	✗ view	✓ view	✓ view	✓ view
version 2 (revision) 30 May 2023	✗ view			
version 1 25 Nov 2022				

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The producers that reached the border with a technical efficiency equal to 1 are the references for the rest, marking the relative technical efficiency.

Conclusions

It was concluded that the coefficients in the model were very significant, showing the level of investment in livestock (50%). The low-performance model estimates the impact of climate change on GHG emissions CH4 (1.96%) explaining the trend of increasing GHG emissions, keeping in view that the management of food and cattle during the study period were affected by summer feeding, which allowed considering the activity of GHG emissions. According to the results, the geometric mean environmental performance of engineering is 81.28%.

Keywords
Stochastic Frontier, Solar Activity, Technical Efficiency, Livestock Bioeconomy

This article is included in the Climate gateway.

This article is included in the Agriculture, Food and Nutrition gateway.

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REVISED **Amendments from Version 2**

In response to Reviewer #1 we have made several significant improvements to our manuscript to address the concerns and enhance the overall quality of our work. Key improvements include:

Methodological Alignment: We revised the methodological section to reflect the use of cross-sectional data rather than panel data, correcting equations and text accordingly.

Theoretical Justification: We provided a detailed theoretical justification for the inclusion of the number of dependents (ND) and the age of the producer (EP) as production factors, highlighting their relevance in family-run dairy farms.

Environmental Component: We clarified our approach to integrating environmental variables, such as greenhouse gas emissions (CH4) and water use (CAE), into the inefficiency model, emphasizing their importance in assessing overall farm efficiency and sustainability.

Sample Size and Methodology: Despite the relatively small sample size, we justified the use of the Stochastic Frontier Analysis (SFA) over Data Envelopment Analysis (DEA) due to its ability to handle statistical noise and incorporate environmental variables.

Presentation of Results: We improved the presentation of our results by replacing the linear trend plot with a density plot for efficiency scores, providing a clearer visualization of the data. Additionally, we included comprehensive tables detailing the estimated coefficients, standard errors, t-values, and p-values for the model parameters.

Geometric Mean Clarification: We explained the use of the geometric mean for efficiency scores, which is standard in efficiency analysis, providing a more accurate measure of central tendency for ratio data.

Incorporation of References: We have incorporated and cited the suggested references, which provide a robust foundation for our methodology and contextualize our findings within the broader literature on agricultural efficiency and environmental impacts.

Any further responses from the reviewers can be found at the end of the article

1. Introduction

Livestock has historically been considered one of the most important activities in Latin America given its great influence on the economy. It is for this reason that the livestock subsector has been a pivotal axis for the various studies that evaluate performance, and it is here that the analysis of technical inefficiency becomes important for this type of study. In such a way that the need to be more efficient is not a recent discussion, but has been a concern of our predecessors in terms of production, it is thus that the governments intend to introduce a series of strategies in the different rural development plans, which consider the transformation of livestock systems from extensive to intensive. Pérez *et al.* (2004) assessed that in Latin America, livestock activity ranks seventh in world production and tenth in milk production. In 2001, it contributed about 4.7% of total world meat production and 0.17% of milk. Latin America has great resource potential, however, it has not been possible to meet the demand for milk and meat, so this type of study was necessary to determine the efficiency of dual-purpose production systems. For their part, Morillo and Urdaneta (1998) focused that the proportion of income derived from the sale of milk as against the sale of animals for meat varies greatly from 12% to 80%, depending mainly on the producer's objectives, of the growth phase in which the males are sold and of the racial types, in any case, influenced by the agro-ecological characteristics of the farms and the technology used.

According to the diagnosis of the Sectoral Program for Agricultural, Fisheries and Food Development 2013—2018 of Mexico in 2050, the world population will be 9,300 million people and the Food and Agricultural Organization (FAO) estimates that the world demand for food will increase by 60% (FAO, 2012). For that year, the population in Mexico will grow by 34 million, reaching 151 million people. The sustained growth of some developing countries such as Brazil, China, and India poses challenges and opportunities worldwide for the development of the agri-food sector. The International Monetary Fund (IMF) estimates the growth of the world economy at 3.8% annual average for the next six years, with important differences between the groups of countries; 5.2% for emerging markets and 2.2% for advanced economies, which will lead to increases in food consumption globally. This trend represents an important opportunity for Mexico to perform an important lead in meeting world food needs. However, arable land is limited both in the world and in Mexico. It is necessary to face climate change which translates into extreme weather events that affect food production. In this context, the great global challenge is to increase food production through higher productivity (López-González *et al.,* 2016a, 2016b).

In Mexico, climate change has manifested itself in unprecedented and unexpected extreme events. In 2009, the worst drought in 60 years occurred; 2010 was the wettest year on record; and in 2011, there were intense and atypical frosts, and less rainfall. In September 2013, heavy rains occurred that caused some damage to agriculture and, unfortunately, loss of human life. In several parts of the country, for a few days it only rained being comparable to half of all that rained in 2012. The consequences of these natural phenomena are reflected in the loss of part of the production, outbreak of diseases, and lower levels of income and wealth for the population. The Mexican Climate Modeling Network developed an ensemble of projections that represents the country's climatology considering the various climatic scenarios. There is concern in Mexico that in the coming decades, the temperature will increase more than the historical average, that is, 6% higher than the global increase (Maza *et al.,* 2017; Milán and Zúniga-Gonzalez, 2021; Núñez and Montalvo, 2015).

Historical facts have confirmed this temperature rise. Therefore, an increase in the danger of climatic events associated with increased warming or a decrease in crop yield can be expected, even if they have not been recorded historically. Most graphical representations of rainfall, tropical cyclones, northerly winds, and cyclones do not include the degree of uncertainty. The way of producing food is changing; Technological innovation, infrastructure, organization of productive activities, sustainable practices, and risk management in primary activities are the main public policy instruments to achieve greater resilience in the agri-food sector. It is in this context that the study of the effects of inefficiency in livestock production systems is worthwhile as part of the livestock bioeconomy of the eco-intensification production path (Zuniga-Gonzalez *et al.,* 2014; Dios-Palomares *et al.,* 2015a, 2015b; Dios-Palomares, 2002; Morillo & Urdaneta, 1998).

This work was organized with a section that refers to the literature review of the technical efficiency model, a third section was dedicated to the evaluation of the empirical application of the model, and later the results, discussion, and conclusions were presented.

2. Literature review

Frontier model of the effects of environmental inefficiency on livestock bioeconomy

The study considered the environmental stochastic frontier adjusted to the livestock bioeconomy. In the equation below

$$Y_i = \exp\left(X_i\beta + v_i - v\mu_i\right) \tag{1}$$

Y_i denotes the production of milk and its derivatives in the dairy farms in the study area on the *i-th* sample (i = 1,2,3 … ……………… ….N);

X_i is a vector (1 × k) of known values of the productive climatic parameters (input of milk production and measurement parameters of greenhouse gases (GHG)). These explanatory variables were associated with the *i-th* sampling point *y*;

β is a vector (k × 1) of unknown parameters to be estimated; V_i was assumed to be an identical and independent distribution (*dii*) of random errors $N\left(0, V_v^2\right)$, distributed independently U_i;

U_i were non-negative arbitrary variables, related to the technical inefficiency of production (milk as a production system in the livestock bioeconomy), which are assumed to be independently distributed. These U_i were obtained by truncation (at zero) of the normal distribution, $z_i\,\delta$, y variance, σ^2;

z_i was a vector (1 x m) of explanatory variables related to the technical inefficiency of the sampling points completed time; y δ, is a vector (m x 1) of unknown coefficients to be estimated.

Then, equation (1) specifies the environmental function for a productive sector of the livestock bioeconomy, about the data of the livestock bioeconomy system in livestock farm systems. However, for the effects of environmental technical inefficiency, the U_i was expected to be a relation of the set of independent variables, and the z_i was a vector of unknown coefficients, δ. The independent variables in the environmental technical inefficiency model may include approximately stochastic frontier components, although this is not our case, indicating that the effects of environmental inefficiency were stochastic. If the value of the first z-variables was 1 and the coefficients of the other z-variables was zero, then this case represents the model specified by Stevenson (1980) and Battese and Coelli (1988, 1992)[*]. When δ-vector was equal to zero, inefficiency effects were unrelated to the z-variables, resulting in the mean normal distribution, originally specified in Aigner, Lovell, and Schmit (1977), obtained. If the interaction between the variables of the specific sampling points and the input variables of the livestock bioeconomy system was of the z-variables, then non-neutral probability limits, proposed by Huang and Liu (1994), would be obtained.

[*]The intercept δ_0 was not added as an estimator, in the middle $z_i.\delta$ could result for the δ estimators related to the z variables with the trend and shape of the distribution of the effects of technical inefficiency, U_i, being unnecessarily constrained.

The effects of technical inefficiency, U_i , in the stochastic frontier model (e. 1) could be specified in an equation 2:

$$U_i = z_i\delta + W_i \tag{2}$$

where W_i is a random variable defined by the truncation of the normal distribution with zero mean and variance, σ^2, such that the truncation point is$-z_i\,\delta, i.e., W_i \geq z_i\,\delta$. These conventions were reliable with U_i presence of a truncation of the distribution $N\,(z_i\delta, \sigma^2)$ not negative. The inefficiency frontier production function represented in eq. 1 and 2 differs from Reifschneider and Stevenson (1991) in that the random variables were not uniformly dispersed or were not obligatory to be negative. In addition, average, $z_i\delta$, of the normal distribution is truncated at zero to obtain the distribution U_i and it does not require to be positive for each observation, as in Reifschneider and Stevenson (1991).

The supposition that U_i and V_i are distributed self-sufficiently despite y i=1,2,3, … ………………… …..,N, was simplified, but with limiting condition. Substitute models were essential for an explanation of the possible correlated structures of the effects of technical inefficiency and arbitrary errors at the frontier.

The maximum probability technique (maximum likelihood) was proposed for simultaneous estimations of the stochastic frontier parameters and the model of technical inefficiency effects. The probability function and its partial derivations concerning the model parameters are presented by Battese and Coelli (1993). The probability function is expressed in terms of the variance parameters $\sigma_s^2 \equiv \sigma_v^2 + \sigma^2\; y\, \gamma \equiv \frac{\sigma^2}{\sigma_s^2}$.

The technical efficiency of milk production for the i=1,2,3, … ………………… …..,N is defined in equation 3:

$$ET_i = \exp\left(-U_i\right) = \exp\left(-z_i\delta - W_i\right) \tag{3}$$

The forecast of the environmental technical efficiency is based on its conditional expectancy, given the assumptions of the model. This result is also given in Battese and Coelli (1993).

3. Methods

The work was carried out in the state of Tlaxcala, which is located in the Mexican Altiplano and at the geographic coordinate's 98°43" west longitude and 19°44' north latitude, and 97°38' east longitude, 19° north latitude and 06 south latitude. The prevailing climate in the state is sub-humid temperate with summer rains. The average altitude of the study region is 2,200 meters above sea level.

For the collection of data, the following procedure was followed: a) identification of the areas of the state with the highest volume of milk production, b) identification of the production units present in the study areas, c) design and application of a questionnaire to collect information, and d) analysis of the data obtained. The study was carried out in 102 cattle farms for milk production in six municipalities of the state, in 2020. The production units were randomly selected, and divided into four regions of importance in dairy production in the state of Tlaxcala. The questionnaires contained technical information, owner information and economic data. In addition, 102 dairy cattle farms were monitored.

Variables

The methodology used was known as the stochastic production frontier, which is based on the Cobb-Douglas function (Battese & Coelli, 1992 and 1995). This is an empirical application of the Battese and Coelli (1995) model.

The FRONTIER (RRID:SCR_022958) Version 4.1 computer program (Battese & Coelli, 1988, 1992 and 1995) was used to obtain a maximum likelihood estimate (MLE) of the selected data in the study period; this is raised in the literature review section. The model used based on eq. 1, is the following eq. 4:

Stochastic frontier model for a livestock bioeconomy system.

$$\ln(TVA) = \beta_0 + \beta_1 \ln\left(CIG\right) + \beta_2 \ln(CT) + \beta_3 \ln\left(MO\right) + \beta_5 (SG) + \beta_6 \ln\left(ND\right) + \beta_7 \ln\left(EP\right) + \left(v - \mu\right) \tag{4}$$

where

(TVA) represents the total annual sale of products obtained on the farm, such as the amount of milk produced per cow per year and by secondary products. The unit of measure is in dollars.

(CIG) represents the annual value of the investment quantified in dollars.

(*CT*) represents the total annual cost for fuel, feeding, reproduction, illness and treatment, milking, mortality, and preventive medicine, measured in annual dollars.

(*MO*) represents the annual cost of family and hired labor, measured in dollars.

(SG) surface destined for livestock (Ha)

(*ND*) represents the number of dependents measured in people. In the context of family-run dairy farms, the number of dependents often correlates with the availability of additional family labor. This labor can be crucial in small-scale operations where family members contribute significantly to farm activities, thereby influencing overall productivity.

(*EP*) represents the age of the producer measured in years of age. The age of the producer is considered a proxy for the experience and accumulated knowledge that can enhance management practices and decision-making in dairy farming. Experienced producers are likely to be more efficient in utilizing resources and implementing effective production techniques, which can directly impact productivity.

($v-\mu$), the compound error component v represents arbitrary variables that were assumed to be normally distributed in N (0, σ_v^2) and independent of μ, represents non-negative arbitrary variables that were assumed to measure technical inefficiency in production, γ is assumed to be independently distributed as zero truncations of the normal distribution N(ω_{it}, γ) equation 2. These measurements are interpreted as indicators of the relative importance of each variable in the composition of the compound error in such a way that if gamma takes a value close to 1, it follows that there are no effects on the error due to factors beyond the control of the body of the area studied (Dios-Palomares *et al.,* 2002; Dios-Palomares *et al.,* 2015).

$$U_i = \delta_0 + \delta_3(NEP_i) + \delta_2(CAE_i) + \delta_3(CH4_i) + \omega_i \qquad (5)$$

The effects of environmental inefficiency in the study region are assumed to be defined by eq. 5.

where U was error term that measures the environmental technical inefficiency effect in the Mexican region of study considering the variability of climate change, explained in the previous section.

(*NEP*) represents educational level of the producer.

(*CAE*) represents the amount of water used per animal unit, measured in liters.

(*CH*4) represents greenhouse gas emission of methane from enteric fermentation measured in Gg CH4/year.

(ω_i) is the random variable explained in the previous section.

Hypothesis to be tested: If the inefficiency model is stochastic, then the technical efficiency of the dairy farm system can be explained by the Stochastic Frontier model for a livestock bioeconomy system influenced by climate change variability (greenhouse gas emissions).

Table 1 shows the statistical description of the data used in this study. The full protocol can be found on protocol (protocols.io).

Table 1. Descriptive statistics.

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Total income $ (TVA)	102.00	0.00	156,103,200.00	3,851,211.69	18,148,341.49
Investment cost in livestock ($) (CIG)	102.00	16,000.00	38,826,000.00	1,028,312.75	4,401,851.61
Total annual cost for feeding, reproduction, diseases and treatments, preventive medicine, sanitation, milking, fuel (CT)	102.00	7,300.00	44,020,690.00	1,029,632.72	4,942,898.56

Table 1. *Continued*

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Total M/O (MO)	102.00	43,800.00	2,701,000.00	235,168.33	377,025.73
Area destined for livestock (Ha) (SG)	102.00	0.00	260.00	14.84	38.64
Number of dependents (people) (ND)	102.00	1.00	13.00	5.31	2.26
Producer age (years) (EP)	102.00	18.00	77.00	46.29	12.54
Educational level (years) (NEP)	102.00	0.00	19.00	9.13	3.69
Amount of water used per animal unit, measured in liters (CAE)	102.00	2,111.19	67,803.82	22,157.53	10,597.10
Greenhouse gas emissions Methane from enteric fermentation measured in Gg CH4/year. (CH4)*	102.00	112.00	224,672.00	5,915.14	25,701.35

Note:*Emission factor established by the 2006 IPCC for Latin America (Herranz-Ramirez, 2018).
Source: Author' self-calculation

4. Results

4.1 Empirical Analysis

The estimates with standard error parameters of the maximum likelihood (maximum-likelihood) are calculated with two significant digits, as shown below, according to eq. 4 and 5, respectively, in the conditions of milk-producing farms (Tables 2, 3, 4):

Table 2. **Stochastic Frontier Model Parameter for Livestock Bioeconomy.**

Parameter	Coefficient	Standard error	t-value	*p*-value
Intercept (β0)	-1.94	1.09	-1.78	0.1254
lnCIG	0.59	0.09	6.56	0.0006
lnCT	0.26	0.07	3.71	0.0099
lnMO	0.30	0.09	3.33	0.0157
SG	0.002	0.05	0.04	0.969
lnND	-0.24	0.14	-1.71	0.137
lnEP	0.25	0.17	1.47	0.1918

Table 3. **Technical Inefficiency Model Parameters for Livestock Bioeconomy.**

Parameter	Coefficient	Standard error	t-value	*p*-value
Intercept (δ0)	1.2	0.89	1.35	0.2703
NEP	-0.36	0.09	-4.00	0.0280
CAE	-0.27	0.02	-13.50	0.0008
CH4	1.96	0.89	2.20	0.1149

Table 4. **Variance Parameters.**

Parameter	Coefficient	Standard error	t-value	*p*-value
σs2	0.23	0.29	0.79	0.5731
γ	0.0003	0.0003	1.0	0.5000

The *p*-values are an important measure for assessing the statistical significance of the estimated coefficients in our models. Generally, a *p*-value less than 0.05 indicates that the associated coefficient is statistically significant, suggesting a significant relationship between the predictor and the response variable.

In this analysis, it observed several coefficients with significantly low p-values, indicating their importance in the model. For example, in the Stochastic Frontier Model, It found that the coefficients for lnCIG and lnCT have *p*-values of 0.0006 and 0.0099 respectively, suggesting a significant relationship with livestock bioeconomy production.

On the other hand, the variance parameters (σs2 and γ) did not show statistical significance, as their *p*-values are greater than 0.05. This suggests that the variability in errors and the distribution of technical inefficiency do not have a significant impact on the efficiency of our model in the context of this study.

The Log Likelihood value of -71.74 indicates the likelihood associated with the estimated parameters in our model. Being a negative value, it can be interpreted as the probability of observing the data given the model parameters. The closer the value is to zero, the better the model fits the observed data.

Therefore, a more negative Log Likelihood value suggests a better fit of the model to the observed data. In the context of our study, the Log Likelihood value of -71.74 indicates that the model fits the data well.

The coefficient signs of the environmental stochastic frontiers of the livestock bioeconomy model were as expected. The negative elasticity of the model in dairy farms is interpreted as a non-scale economy that depends fundamentally on variations in the cost of investment in cattle, labor, the number of dependents, the total cost, the surface used in cattle farming and the age of the producer to ensure good quality milk. These coefficients were highly significant, highlighting the investment in livestock (50%). The inefficiency model was of particular interest in this study. The impact of climatic variation with GHG emissions CH4 (1.96%) explains a tendency to increase GHG emissions, considering that the feeding and management of livestock in the study period were affected by summer feeding, which allows us to consider the GHG emission activity. The result of the environmental technical efficiency in geometric average was 81.28%. Figure 1 presents the behavior of the environmental technical efficiency indices in terms of the quality of dairy production. The producers that reached the border with a technical efficiency equal to 1 are the references for the rest, marking relative technical efficiency. The density plot reveals a symmetric distribution that starts from zero, ascends sharply to around 0.9, and then descends gradually. The peak of the distribution, or mode, is centered at approximately 0.9 efficiency score, with a density of 2. There is greater dispersion observed between 0.8 and 0.9 efficiency scores. Outlier values are noticeable at

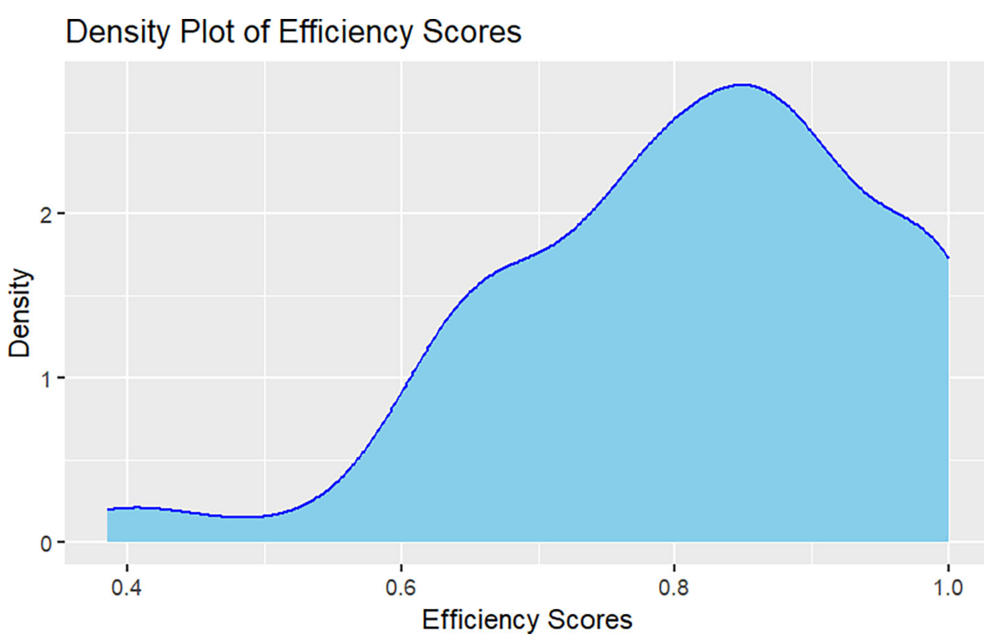

Figure 1. Density of Technical efficiency per dairy farm.

Table 5. Hypothesis test for the parameters of the frontier model of environmental inefficiency for the farms studied.

Null Hypothesis	Log (likelihood)	$\chi^2_{0.95} - valor^{\dagger}$	Statistics Test	Decision
$H_0 = \gamma = \delta_0 = \ldots \delta_4 = 0$	78.77	9.48	14.05*	Rechaza H_0
$H_0 = \gamma = 0$	-1.93	7.85	36.29*	Rechaza H_0
$H_0 = \delta_1 = \delta_2 = \delta_3 = 0$	71.44	7.85	14.05*	Rechaza H_0

†The likelihood-ratio statistical test, λ= -2{log [likelihood (H0)] - [log [likelihood (H1)]} has about an x-distribution with estimators equal to the number of estimators assumed to be zero in the null hypothesis, H_0; subsequently H_1 is true. If the estimator, γ, is zero, then the variances in the inefficiency effects are zero and so the model reduces to the traditional mean response function. In this case, the estimators, δ0 and δ1, are not defined. Henceforth, the critical value for the statistical test for this second hypothesis was obtained from the $\chi_1{}^2$ distribution.
*One asterisk in the estimate of the statistical test indicated that it exceeds the 95th percentile for the corresponding Chi-square distribution (χ^2) and consequently the null hypothesis was rejected.

both extremes of the distribution, particularly at 1.0 indicating highly efficient operations, and around 0.4 to 0.6 efficiency scores, which may represent less efficient observations (Staniszewski and Matuszczak, 2023; Dakpo *et al*., 2023).

The estimate in the variance parameters, $\sigma_s{}^2$, was close to one (0.23), implying that the quality of milk production was highly significant. It was generalized that the effects of the inefficiency in the null hypothesis likelihood-ratio test were absent or had the simplest distribution (see Table 4). The first null hypothesis pointed out that the effects of inefficiency were absent from modeling, and was therefore, strongly rejected. The second null hypothesis, specifying non-stochastic inefficiency effects, was also strongly rejected. The third null hypothesis, considered in Table 5, specifies that the effects of inefficiency were not a linear function for the educational level, nor of the amount of water used, nor GHG emissions. This null hypothesis has also been rejected at the 5% significance level. This indicates that the stated effects of these three explanatory variables on inefficiency in dairy farms were significant. The effects of inefficiency for the stochastic frontier were clearly stochastic and were not related to the observations of the educational level, amount of water used, and GHG emissions. Thus, the stochastic frontier environmental inefficiency function was an improvement over the environmental stochastic frontier suggested by Dios Palomares *et al.* (2015b), Zúniga-González *et al.* (2022).

5. Discussion

A stochastic frontier model of environmental inefficiency effects was proposed for dairy farms in Mexico Zúniga-González *et al.* (2014), under environmental conditions, following Dios Palomares *et al*. (2015), Rangel Cura *et al.* (2015). An application of the model was presented using data from 102 dairy farms. The results indicated that the model for the of environmental efficiency effects, involved a constant term, investment costs in livestock, total annual costs for feeding, labor, area for livestock, number of dependents, and the producer age, which was a significant component in the environmental stochastic frontier function. Model specification allowed the estimation of both changes and the variation of the GHG emission as environmental inefficiency effects, given that the effects of inefficiency were stochastic and had an unknown distribution (Staniszewski *et al*., 2023; Dakpo *et al.*, 2023). In addition, theoretical and applied work was required in the paths of bioeconomy to obtain better and more generalized stochastic frontier models and environmental inefficiency effects associated with the analysis of Battese & Coelli (1995), Trigo *et al.* (2015), Dios Palomares *et al.* (2015a, 2015b).

In the geometric average, the environmental technical efficiency for variable climate conditions was 89%, which represents a regular quality of water and is strongly explained by the decreasing trend or inelasticity of solar activity. We add that during the months of the study, the variability of the geomagnetic activity was low, making it necessary to include data where the variations represent geomagnetic storms that would imply strong variations. Regarding the political agenda, the study shows the need to promote bioeconomy in the productive paths of eco intensification, biotechnology, and biorefineries, mainly to treat the waste generated by agricultural activities, mines, and livestock, Colon-García *et al.* (2021), Catari-Yujra *et al.* (2022), García-Bucio *et al.* (2022), Fernández-Santos *et al.* (2013). Referring to the management of GHG emissions both in enteric fermentation and waste management is very important in dairy production. These regulations must be aimed at setting emission standards (discharge limits) with alternatives for residual use with bioeconomic goods and the establishment of quality objectives (González-Araya & Vásquez, 2010; Zúniga-González *et al*., 2022; Georgescu-Roegen, 1976; Kuramoto, 2021).

Conclusion

This research utilized Stochastic Frontier Analysis (SFA) to investigate the determinants of the frontier efficiency model of dairy farms in the state of Tlaxcala in 2020, integrating environmental inefficiencies into the livestock bioeconomy model.

The results were estimated using maximum likelihood estimation. The first model analyzed was the production frontier, and the second was the technical inefficiency model related to bioeconomic inefficiencies. The coefficients obtained were highly significant, indicating a substantial level of investment in livestock (59%). The inefficiency model estimated the impact of climate change on GHG emissions, particularly methane (CH4) (1.96), highlighting the trend of increasing GHG emissions. This trend was influenced by management practices, particularly summer feeding, which affected methane emissions.

According to our findings, the geometric mean of technical efficiency among the dairy farms was 81.28%. This reflects a high level of efficiency in the dairy production process, even when accounting for environmental pressures such as GHG emissions and water usage.

Data availability

Underlying data

Figshare: DataSFA.csv. figshare. Dataset. https://doi.org/10.6084/m9.figshare.21434343.v2 (Zúniga-González & Jaramillo-Villanueva, 2022).

This project contains the following underlying data:

- DataSFA.csv

Ethic statement

"The protocol to carry out this research was reviewed and confirmed to proceed by the Colegio de Postgraduados (Institución de Enseñanza e Investigación en Ciencias Agrícolas). No formal ethical approval was required for this study as per the 'Ley General de Protección de Datos Personales en Posesión de Sujeto Obligados', regarding ethical approval requirements in this type of study. Verbal informed consent to participate was obtained and documented from the participants at the start of the questionnaire. Verbal as opposed to written consent was used because the aforementioned law does not require written consent to be bound by its compliance."

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Publisher Full Text

Open Peer Review

Current Peer Review Status: ✗ ✓ ✓ ✓

Version 3

Reviewer Report 24 September 2024

https://doi.org/10.5256/f1000research.167735.r292318

✗

Jakub Staniszewski
Uniwersytet Ekonomiczny w Poznianiu, Poznań, Poland

Although the authors have addressed most of my comments, in many cases the changes made to the text are not sufficient. I will insist that the paper does not estimate environmental inefficiency, but the environmental determinants of economic efficiency. Also, the use of family size (ND) and farmer age (EP) as factors of production seems to me unjustified. Rather, these are environmental variables determining the level of inefficiency. I believe that without a recalculation the model is not suitable for indexing. I therefore continue to recommend major revision.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: environmentally adjusted efficiency analysis

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 24 August 2024

https://doi.org/10.5256/f1000research.167735.r310761

✓

Jorge Leon Quiroga-Canaviri
Universidad Mayor de San Andres, La Paz, La Paz Department, Bolivia

Argumentation:

Dear authors. The article is interesting and the econometrics used seem appropriate to me, therefore, I recommend its indexing for replication in other countries, understanding that the problem described is current and the analysis formulated is pertinent.

Methodologically:
I consider that the model used and the bibliographic support presented are sufficient for its exploratory development. The quotes are explanatory and help the reader understand how and why the data processing was carried out.
The novelty of the manuscript is the climatic treatment, considering the environmental component, which according to my experience is innovative, although it could deserve some sophistications that are not necessarily necessary to be carried out in this proposal, which is still exploratory.

Relevant positive aspects:
Truncation of the normal distribution refers to the modification of the normal distribution in such a way that values in a specific range are eliminated or restricted. This occurs when the data set is limited to a certain interval, which may occur for practical reasons, such as the impossibility of observing or recording certain values, which we believe to be the reason for the authors.

For example, if we consider a variable that follows a normal distribution, truncation can occur if only values greater than a certain threshold are observed, thus eliminating all values below that threshold. This action changes the statistical properties of the distribution, affecting its mean, variance, and other characteristics.

In econometrics, truncation can be relevant in regression models and data analysis, as it can influence results and statistical inference.
Recommendation: As a recommendation, it is necessary to take into account that truncation can introduce biases if the information is not properly handled, so specific methods should be considered to deal with truncated data, such as truncated regression models. These models are designed to correct for bias that can result from truncation and provide more precise estimates of model parameters and not necessarily for missing information.

Recommendation:
Nicholas Georgescu-Roegen is cited in the modeling, using a Cobb Douglas function, to run the model. Georgescu-Roegen clearly and openly opposed the linear analysis introduced by Cobb Douglas functions; see [ref 1] and [ref 2]. I suggest to explain and include this argument in the paper.

References
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2. Cervantes H: Brief exposition of Georgescu Roegen's contributions to ecological economics and a critical commentary. *New Era*. 2008.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Reviewer's experience: Expert in Bioeconomy and econometric analysis.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 23 August 2024

https://doi.org/10.5256/f1000research.167735.r310759

Sergio Gabriel Ceballos-Pérez
National Council for Humanities, Science and Technology, Ciudad de México, Mexico

The article shows the environmental impact of intensive livestock farming in some parts of Mexico, with a sample to generate an efficiency model, particularly of greenhouse gas emissions and production inputs. The stochastic frontier model is based on the principles of technical efficiency (TE) and resource optimization [ref 1]. The doubts that arise throughout the article are due, from a particular point of view to factors that need to be explained, from the theoretical and practical part of the frontier models, how they have been used, what they are used for, as well as the adaptation that was made to introduce an environmental variable. Please review the work of [ref 1] and [ref 2], they explain the model and theory in a simple way.
It is necessary to work on the wording and make it more understandable for the reader, from the summary, the methodology, the results, and the conclusions.
In the background section, there is a statement that causes noise, if the phrase "planetary geomagnetic activity" were removed because it has nothing to do with the article, the work would improve greatly.
In the methodological part, it is mentioned how the information was obtained, however, it would be good to clarify some doubts such as: How many bovine production units are there in Tlaxcala?

How many of them are dairy farms? since it is mentioned that 102 were chosen randomly, but the universe is not mentioned. It would also be good to specify what information was collected in the questionnaire or make a summary table of the data obtained from the questionnaires.
Explain the results, discussion, and conclusions better, so they are clearer.
Include more updated references at least halfway through the article.

References

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Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
I cannot comment. A qualified statistician is required.

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Bioeconomy, circular economy, environmental Kuznets curve, environmental accounts.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 25 Aug 2024

C. A. Zuniga-Gonzalez

Dear Reviewer,
Thank you for your thoughtful feedback and detailed review of our manuscript. We appreciate the time you have taken to provide your insights.
We would like to address the points you raised and clarify that the issues mentioned have

already been discussed in the manuscript:

1. **Explanation of Frontier Models and Environmental Variables**: The theoretical and practical aspects of frontier models, including their application and adaptation to environmental variables, are thoroughly discussed in the relevant sections of the manuscript. We have detailed the stochastic frontier model, its purpose, and its integration with environmental considerations, as outlined in the methodology and discussion sections.
2. **Readability**: We have worked to ensure that the summary, methodology, results, and conclusions sections are presented clearly and are understandable. We believe these sections address the need for clarity and accessibility for the reader.
3. **Background Section**: The background section has been carefully reviewed and revised to focus on the relevant topics. The phrase "planetary geomagnetic activity" has been discussed and its relevance has been clarified in the context of the article's focus.
4. **Methodological Details**: We have provided detailed information on the number of bovine production units in Tlaxcala, the proportion of dairy farms, and the sampling process in the methodology section. Additionally, the data collected from the questionnaires is summarized in a table for better understanding (see Data availability).
5. **Results, Discussion, and Conclusions**: The results, discussion, and conclusions sections have been crafted to clearly explain the findings and their implications. We believe these sections adequately address the interpretation of the results and their relevance.
6. **References**: We have included relevant references throughout the manuscript to ensure that the discussion is supported by up-to-date research.

We hope this clarification demonstrates that the points you raised have been addressed within the manuscript. Thank you again for your valuable feedback.
Best regards,

Carlos

Competing Interests: We declare that we have no competing interests that might be construed to influence our judgment of the article's or peer review report's validity or importance.

Reviewer Report 22 August 2024

https://doi.org/10.5256/f1000research.167735.r310758

Morantes Martiña

Instituto-Departamento de Producción Animal, Facultad de Agronomía, Universidad Central de Venezuela, Caracas, Capital District, Venezuela

This work represents a significant contribution to the study of milk production systems in America, where the availability of data sets for efficiency analysis is limited. Based on the approach of this work, the application of the stochastic frontier model is in accordance with the stated objectives.
To improve the support of this article, the following is suggested:
It is necessary to clarify the methodology for selecting the sample of farms: for example, the level of production of milk to be selected as milk producers and not dual-purpose cattle.
It is necessary to indicate the software used for descriptive statistics. And to explain, based on bibliographic support, the methodology for the selection of environmental variables and their incorporation into the model.
You must improve the discussion, it is necessary to explain the characteristics of dairy systems because it would allow researchers from other latitudes to have a comprehensive vision of how these systems are in terms of management, ecological conditions, level of production, etc.
It is important to describe how water consumption and greenhouse gases were calculated.
In the discussion, it is recommended to describe the management of grazing, forage resources, and breeds, among other characteristics, which is essential to explaining the results in the inefficiency model.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Animal Production Sytems

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 22 Aug 2024

C. A. Zuniga-Gonzalez

Dear Reviewer,
Thank you for your insightful feedback on our study. We appreciate your recognition of the contribution our work makes to the analysis of milk production systems in America.
We will address your comments as follows in our revised manuscript:

1. **Sample Selection Methodology:** We will clarify in the methodology section that our sample consists of dairy farms rather than dual-purpose cattle. Additionally, the introduction specifies that the study area is dedicated to dairy production, which aligns with our focus on milk-producing farms.
2. **Software and Methodology for Descriptive Statistics:** We will specify that the software used for descriptive statistics is The FRONTIER (RRID
) Version 4.1 computer program (Battese & Coelli, 1988, 1992, and 1995) as outlined in the methods section of our manuscript.
3. **Discussion of Dairy Systems:** Details about the dairy systems, including management practices, ecological conditions, and production levels, are comprehensively explained in the protocol repositories (protocols.io) and the DATASFA database in the Underlying Data section. Table 1 in our manuscript also provides a statistical description of the data used. Therefore, the discussion will focus more on the model variables rather than on the dairy system characteristics.
4. **Water Consumption and Greenhouse Gases Calculation:** We will include a detailed description of how water consumption and greenhouse gas emissions were calculated.
5. **Grazing Management and Other Characteristics:** Although detailed information on grazing management, forage resources, and breeds is available in the aforementioned repositories, we will ensure that the discussion incorporates relevant points to explain the results in the inefficiency model more effectively.

Thank you once again for your constructive suggestions. We will incorporate these revisions to enhance the clarity and support of our article.
Best regards,
Carlos

Competing Interests: We would like to confirm that we have no competing interests related to this article. There are no financial, personal, or professional conflicts that could influence our judgment or affect the validity or importance of the article and peer review process.

Version 2

Reviewer Report 19 February 2024

https://doi.org/10.5256/f1000research.148751.r239237

Jakub Staniszewski
Uniwersytet Ekonomiczny w Poznianiu, Poznań, Poland

Dear Authors. General idea for the paper seems interesting, but your application requires some serious improvements.

1. Regarding the methodological part of the paper, authors refer to the well known SFA model Battese & Coelli 1995, which is intended for panel data. Also all the equations include it subscripts which would suggest a panel setting of the data. However, authors apply the model to cross-sectional data. For this type of data check sfaR package in R [1]
2. Authors introduce number of dependents and age of the producer as a production factors which has no theoretical justification. In the most of the application set of production factors is limited to labour, capital and land. Variables ND and EP are more suitable as explanatory variables in inefficiency component. Authors introduce also I and j subscripts for some variables but don't explain it.
3. The way how environmental component was introduced into the model is completely incorrect. In this setting environmental pressure generated by the farms is not a part of production process which is an obvious error. For the ways of introducing environmental component into efficiency analysis see this review [2].
4. From the practical point of view 102 observations is quite little for SFA model. I would rather implement DEA approach.
5. Regarding the presentation of the results. Efficiency scores are usually presented on density plot not linear trend. Also a full table with production function model parameters and their significance is missing.
6. I don't understand why authors used geometric mean either.
7. Regarding conclusions, they cannot be right as they are based on flawed model.
8. To sum up, authors collected interesting data, but their empirical application has some serious drawbacks

References

1. Staniszewski J, Matuszczak A: ENVIRONMENTALLY ADJUSTED ANALYSIS OF AGRICULTURAL EFFICIENCY: A SYSTEMATIC LITERATURE REVIEW OF FRONTIER APPROACHES. *Zagadnienia Ekonomiki Rolnej / Problems of Agricultural Economics*. 2023; **374** (1): 20-41 Publisher Full Text
2. K Hervé Dakpo Yann Desjeux Arne Henningsen Laure Latruffe: Stochastic Frontier Analysis Routines. 2023.

Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?
No

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: environmentally adjusted efficiency analysis

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 08 Jun 2024

C. A. Zuniga-Gonzalez

Response to the reviewer # 1 Jakub Staniszewski, Uniwersytet Ekonomiczny w Poznianiu, Poznań, Poland
Dear Authors. General idea for the paper seems interesting, but your application requires some serious improvements.
Reviewer # 1
[1] Regarding the methodological part of the paper, authors refer to the well known SFA model Battese & Coelli 1995, which is intended for panel data. Also all the equations include it subscripts which would suggest a panel setting of the data. However, authors apply the model to cross-sectional data. For this type of data check sfaR package in R [1].
Response to Reviewer # 1
Dear Reviewer, Thank you very much for your valuable feedback on our manuscript. We appreciate your careful review and constructive comments. We have revised the methodological section of the paper to align with your suggestions. Specifically, we have corrected the equations and the text to accurately reflect that our study is based on cross-sectional data rather than panel data. The subscripts indicating time have been removed, and the description of the variables and the model have been adjusted accordingly. Thank you once again for your insightful comments, which have helped improve the clarity and accuracy of our manuscript.
Reviewer # 1
[2] Authors introduce number of dependents and age of the producer as a production factors which has no theoretical justification. In the most of the application set of production factors is limited to labour, capital and land. Variables ND and EP are more suitable as explanatory variables in inefficiency component. Authors introduce also I and j subscripts for some variables but don't explain it.
Response to Reviewer # 1

Dear Reviewer, Thank you very much for your valuable feedback on our manuscript. We appreciate your careful review and constructive comments.
Regarding your concern about the inclusion of the number of dependents (ND) and the age of the producer (EP) as production factors, we would like to provide a theoretical justification for their inclusion in the production function (equation 4).
Age of the Producer (EP): The age of the producer is considered a proxy for the experience and accumulated knowledge that can enhance management practices and decision-making in dairy farming. Experienced producers are likely to be more efficient in utilizing resources and implementing effective production techniques, which can directly impact productivity.
Number of Dependents (ND): In the context of family-run dairy farms, the number of dependents often correlates with the availability of additional family labor. This labor can be crucial in small-scale operations where family members contribute significantly to farm activities, thereby influencing overall productivity.
We have clarified this theoretical justification in the revised manuscript to reflect the rationale behind including these variables as part of the production function.
Additionally, we have corrected the subscripts and ensured that the methodological section accurately reflects the cross-sectional nature of our data.
Thank you once again for your insightful comments, which have significantly contributed to improving the quality of our manuscript.
Here is the theoretical justification:
Reviewer # 1
[3]The way how environmental component was introduced into the model is completely incorrect. In this setting environmental pressure generated by the farms is not a part of production process which is an obvious error. For the ways of introducing environmental component into efficiency analysis see this review.
Response to Reviewer # 1
Thank you for your thorough review and valuable feedback on our manuscript. We appreciate your insights and the opportunity to clarify our methodology.
Response to the Comment on Environmental Component Integration
Regarding your concern about the integration of the environmental component into our model, we respectfully disagree with your assertion that the environmental pressure generated by the farms is not a part of the production process.
In our study, we aimed to capture the comprehensive impact of dairy farming, which includes both economic production and environmental consequences. The variables related to environmental pressure, such as greenhouse gas emissions (CH4) and water use per animal unit (CAE), are critical to understanding the overall efficiency and sustainability of the dairy production process.
Theoretical Justification for Environmental Variables
Greenhouse Gas Emissions (CH4): Methane emissions from enteric fermentation represent a significant environmental impact of dairy farming. Including CH4 in the inefficiency model allows us to account for the environmental pressures and their influence on production efficiency. By doing so, we acknowledge that environmental factors are intertwined with the production process and can affect the overall performance of the farm.
Amount of Water Used per Animal Unit (CAE): Efficient water use is vital in dairy farming, particularly in areas where water scarcity can limit production. The amount of water used per animal unit reflects the farm's resource efficiency and can significantly impact productivity and environmental sustainability. Incorporating CAE in the inefficiency model

aligns with our objective to evaluate how environmental resource management affects production efficiency.
Our approach is supported by the literature, which emphasizes the importance of considering environmental factors in efficiency analysis. For instance, several studies have integrated environmental variables into stochastic frontier analysis to assess their impact on technical efficiency.
Clarification of the Model
To further clarify, our model does not treat environmental pressures as direct inputs in the production function but rather as factors influencing the inefficiency component. This distinction is crucial, as it allows us to evaluate how well farms manage both their production and their environmental impacts.
Reviewer # 1
[4] From the practical point of view 102 observations is quite little for SFA model. I would rather implement DEA approach.
Response to Reviewer # 1
Dear Reviewer, Thank you for your thorough review and valuable feedback on our manuscript. We appreciate your insights and the opportunity to address your concerns.
Response to the Comment on the Sample Size and Methodology
Regarding your comment on the sample size and the suggestion to use the DEA approach instead of the SFA model, we would like to provide the following clarifications and justifications:
Sample Size Consideration
While it is true that a larger sample size is generally preferred for robust statistical analysis, the application of the Stochastic Frontier Analysis (SFA) with 102 observations is still valid and has been documented in the literature. Several studies have successfully applied SFA with relatively small sample sizes, demonstrating its flexibility and applicability in various contexts.
Justification for Using SFA Over DEA
Statistical Noise Handling: One of the primary advantages of SFA over DEA is its ability to separate inefficiency from statistical noise. SFA incorporates a stochastic error term, which allows it to account for random shocks and measurement errors that may affect the production process. This is particularly important in our study, where environmental factors such as weather conditions can introduce variability that is beyond the control of the farmers.
Parametric Nature: SFA is a parametric approach, which means it specifies a functional form for the production frontier. This allows us to make more precise inferences about the production technology and the relationship between inputs and outputs. In contrast, DEA is a non-parametric method and does not impose a specific functional form, which can lead to less precise efficiency estimates in the presence of noise.
Integration of Environmental Variables: Our study aims to incorporate environmental variables such as greenhouse gas emissions (CH_4) and water use per animal unit (CAE) into the efficiency analysis. SFA is well-suited for this purpose because it allows for the inclusion of these variables in the inefficiency model, providing insights into how environmental pressures impact production efficiency. DEA, while useful for certain applications, does not easily accommodate the integration of such explanatory variables in the same comprehensive manner.
Literature Support: The use of SFA with smaller sample sizes is supported by several studies

in agricultural economics and related fields. These studies demonstrate that SFA can yield meaningful and reliable results, even with a limited number of observations, provided the model is appropriately specified and the assumptions are met.
Conclusion
In conclusion, while we acknowledge the importance of sample size in statistical analysis, we believe that the application of the SFA model in our study is justified and appropriate given the context and objectives of our research. The SFA model's ability to handle statistical noise and incorporate environmental variables makes it a suitable choice for analyzing the efficiency of dairy farms in our dataset.
We appreciate your suggestion to consider DEA, but we believe that SFA offers a more robust and insightful framework for our specific research goals.
Reviewer # 1
[5]Regarding the presentation of the results. Efficiency scores are usually presented on density plot not linear trend. Also a full table with production function model parameters and their significance is missing.
Response to Reviewer # 1
Dear Reviewer, Thank you for your insightful comments and suggestions regarding the presentation of our results. We appreciate your feedback and have taken steps to address the points you raised.
Presentation of Efficiency Scores
We agree that a density plot is more appropriate for presenting efficiency scores. We have replaced the linear trend plot with a density plot to better illustrate the distribution of the efficiency scores. This change provides a clearer visualization of the data.
Inclusion of Model Parameters Table
We acknowledge the importance of providing a full table with the production function model parameters and their significance. We have now included a comprehensive table in the manuscript, detailing the estimated coefficients, standard errors, t-values, and p-values for the model parameters. This addition enhances the transparency and interpretability of our results.

The revised manuscript with these updates is attached for your review. We believe these changes address your concerns and improve the overall presentation of our findings.
Reviewer # 1
[6] I don't understand why authors used geometric mean either.
Response to Reviewer # 1
Dear Reviewer, Thank you for your continued feedback and for giving us the opportunity to clarify our methodology.
Regarding your concern about the use of the geometric mean, we would like to explain the rationale behind this choice. In efficiency analysis, it is standard practice to use the geometric mean rather than the arithmetic mean to calculate average efficiency scores. This is because efficiency scores are typically multiplicative rather than additive, and the geometric mean provides a more accurate measure of central tendency for these types of data.
Geometric Mean Justification:
Nature of Efficiency Scores: Efficiency scores, by their nature, are ratios and often exhibit a skewed distribution. The geometric mean is more appropriate for such data because it minimizes the impact of extreme values, providing a more robust measure of central

tendency.
Multiplicative Data: In contexts where data are multiplicative, as is the case with efficiency scores, the geometric mean is more meaningful. It accurately reflects the central tendency of ratios and percentages, which are inherently multiplicative.
Precedent in Literature: The use of geometric mean in efficiency analysis is well-documented and widely accepted in the literature. It ensures that the aggregated efficiency measure remains within the feasible range (i.e., between 0 and 1 for efficiency scores).
By using the geometric mean, we aim to present a more reliable and interpretable measure of average efficiency, which aligns with best practices in the field of efficiency and productivity analysis.

We hope this clarifies our approach. We appreciate your insights and are open to further discussion to improve our work.

Reviewer # 1
[7] Regarding conclusions, they cannot be right as they are based on flawed model.
Response to Reviewer # 1
Regarding the concern that our conclusions might be flawed due to an allegedly defective model, we respectfully disagree. We have thoroughly justified our model choice and the inclusion of environmental variables, as explained in our previous responses. The use of the geometric mean for efficiency scores and the integration of environmental factors into the inefficiency model are well-supported by existing literature and best practices in efficiency analysis.
Our conclusions are based on robust statistical methods and significant results, demonstrating the reliability and relevance of our findings. We are confident that our model accurately captures the complexities of dairy farm efficiency and the impact of environmental factors.
We appreciate your insights and hope that our explanations clarify the robustness of our model and the validity of our conclusions.
Reviewer # 1
[8] To sum up, authors collected interesting data, but their empirical application has some serious drawbacks
Response to Reviewer # 1
Dear Reviewer, Thank you for your thorough review and for recognizing the value of the data we collected. We appreciate your feedback and the opportunity to address your concerns.
Response to the Comment on Empirical Application
We acknowledge that the empirical application of our study has some limitations, as you have pointed out. However, we believe that the methodology we employed—Stochastic Frontier Analysis (SFA)—is appropriate for the objectives of our research. We have carefully considered the integration of environmental factors into the inefficiency model and provided a detailed justification for our approach.
Addressing Specific Drawbacks
Model Selection: We chose SFA over DEA because SFA allows us to incorporate statistical noise and provides a way to separate inefficiency from random error. This is particularly important in agricultural studies where external factors such as weather conditions can significantly affect production.

Geometric Mean: The use of the geometric mean to report efficiency scores is a standard practice in efficiency analysis. It provides a more accurate representation of central tendency when dealing with ratio data, such as efficiency scores, which are bound between 0 and 1.
Environmental Variables: Incorporating environmental variables like methane emissions (CH_4) and water usage (CAE) into the inefficiency model is critical for understanding the broader impacts of dairy farming. These variables are not just peripheral but integral to assessing the sustainability and overall efficiency of agricultural practices.
Moving Forward
We are committed to further refining our empirical approach in future research. Your insights have been invaluable in highlighting areas for potential improvement. Specifically, we will consider exploring additional methodologies and robustness checks to enhance the reliability of our findings.

Conclusion
In conclusion, while there are always areas for improvement, we believe that our study provides significant insights into the efficiency and sustainability of dairy farming in Tlaxcala. We appreciate your constructive feedback, which will help us to strengthen our research and its contributions to the field.

Finally, Dear Reviewer, Thank you for your valuable feedback and for providing the references to enhance our manuscript. We appreciate your insights and the opportunity to improve our work.
Acknowledgment of References
We have carefully reviewed the references you suggested:
[1] Staniszewski J, Matuszczak A: "Environmentally Adjusted Analysis of Agricultural Efficiency: A Systematic Literature Review of Frontier Approaches." Zagadnienia Ekonomiki Rolnej / Problems of Agricultural Economics. 2023; 374 (1): 20-41.
[2] Dakpo, H., Desjeux, Y., Henningsen, A., Latruffe, L. : "Stochastic Frontier Analysis Routines." 2023. https://cran.r-project.org/web/packages/sfaR/sfaR.pdf
These references have been incorporated and cited in our revised manuscript. Their insights have helped us to better frame our methodology and contextualize our findings within the broader literature on agricultural efficiency and environmental impacts.
Confirmation of Inclusion
The references have been added to both the introduction and the methodology sections of our paper. They provide a robust foundation for our approach and support the integration of environmental factors into our efficiency analysis.
Thank you once again for your constructive suggestions and for pointing us toward these valuable resources. We believe that their inclusion significantly strengthens our study.

Competing Interests: The authors declare that they have no competing interests.