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Key Factors of Competitiveness and Sustainability in Livestock Systems of The Andean-Amazonian Piedmont

Factores clave de competitividad y sostenibilidad en los sistemas ganaderos de Piedemonte Amazónico Colombiano

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ABSTRACT

The objective was to identify factors of competitiveness and sustainability in livestock systems of The Andean-Amazonian Piedmont. In a sample of 60 farms in the area, a survey aimed at producers was implemented to identify internal and external factors for competitiveness and sustainability. Data envelopment analysis was used to measure technical efficiency and an econometric model to identify the determinants of competitiveness and sustainability. The key factors towards competitiveness were the profitability of the cattle and the forest extension within the farms. The key factors towards sustainability were the reduction of environmental impacts of deforestation to increase carbon storage and the enhancement of ecosystem services. The increase of profitability and the establishment of sustainable systems of livestock production are the rallying points to improve competitiveness and sustainability in livestock of the Amazonian foothills.

Keywords: *Carbon capture, Ecosystem service, Comparative advantage.*
Jel code: Q01, Q13

RESUMEN

El objetivo fue identificar los factores tanto de la competitividad como de la sostenibilidad en los sistemas ganaderos del Piedemonte Amazónico Colombiano. En una muestra de 60 fincas de la zona, se aplicó una encuesta dirigida a los productores para identificar los factores. Se midió la eficiencia técnica y, mediante un modelo econométrico, se identificaron los determinantes de la competitividad y la sostenibilidad. Los factores clave para la competitividad fueron la rentabilidad del ganado y la extensión forestal dentro de las fincas. Los factores clave para la sostenibilidad fueron la reducción de los impactos ambientales de la deforestación para aumentar el almacenamiento de carbono y la mejora de los servicios de los ecosistemas. El aumento de la rentabilidad y el establecimiento de sistemas sostenibles de producción ganadera son el punto de encuentro para mejorar la competitividad y sostenibilidad de la ganadería del Piedemonte Amazónico.

Palabras clave: Captura de carbono, servicio del ecosistema, ventaja comparativa
Código JEL: Q01, Q13

INTRODUCTION

The livestock sector is important to the economy of Colombia and its Amazon region. It represents 1.4% of the national GDP and 21.8% of the GDP of the agricultural sector (DANE, 2021). It produces 6% of national employment and 19% of employment in the agricultural sector, and 7.9% of the head of cattle in Colombia is produced in the Amazon region (FEDEGAN, 2021). However, the livestock sector has not been competitive due to low levels of productivity and quality compared to other countries, and due to the predominance of extensive livestock models in the Amazon region (Ramírez and De Aguas, 2021). Their international markets take place with nearby countries with low-quality requirements (Pertuz-Martínez and Elías-Caro, 2019).

The Amazon region contributes about 0.9% of the country's GDP and 1.8% of the primary sector (DANE, 2021). The Amazon has fragile soils for the development of livestock (Martínez and Zink, 2004), but it has been an established economic activity since the 1950s (Arcila, 2011). Around 98% of the livestock systems in the Amazon foothills are considered traditional, 1.8% are in transition towards sustainable production models and 0.2% have some sustainable production model (agroforestry, silvopastoral, agro-silvopastoral) (Pardo- Rozo, Muñoz-Ramos and Velásquez-Restrepo, 2020).

The expansion of the agricultural frontier has caused deforestation, loss of biodiversity, species displacement, contamination of water bodies, soils, and changes in the dynamics of water and microclimatic regulation (Pardo *et al*., 2021). The emission of 26% of greenhouse gases in Colombia is attributed to the agricultural sector (Yáñez *et al*., 2020). The Colombian Amazon contains endogenous ecosystems and strategic environmental services, such as carbon capture and storage and regulation of the water cycle (Roucoux *et al*., 2017), which are important in mitigating climate change. Environmental services in the Amazon are considered a comparative advantage (Olaya, Dussan and Plazas, 2017). Therefore, the Amazon livestock systems have comparative advantages that must be harnessed to improve competitiveness.

This research aims to identify key factors of competitiveness and sustainability in livestock systems in the Amazon foothills. The research is part of the world policy of the Sustainable Development Goals (United Nations, 2015) and national, regional, and local development plans for rural development (ECLAC, FAO and IICA, 2020). The resulting information will allow the design of guidelines for decision-makers aimed at strengthening the Colombian agricultural policy.

THEORETICAL CONCEPTUAL FRAMEWORK

The concept of competitiveness. Competitiveness is a concept that, since the beginning of the millennium, has acquired greater complexity through different approaches and disciplines from the first approaches of Chandler (1962), Ansoff (1965), Krugman (1994), and Porter (1998). This last author defines competitiveness as being different or competitiveness as the survival capacity and positioning of an organization or company in the market with a performance above the average. The author mentions the creation of strategies to achieve competitiveness such as the cost leadership strategy, the differentiation strategy, and the focus strategy. Competitiveness can also be defined as a process of market integration between countries and the ability to develop the economy based on its operational productivity and the opening of markets, which improves the quality of life of the inhabitants (Porter, 2008).

For companies, sectors, or countries to become competitive, they must have operational and allocative efficiency. Among the concepts associated with competitiveness, we can find productivity, efficiency, globalization, the opening of markets, and in general the optimization of economic, technological, and economic processes. Although productivity is restricted to the optimization of a productive apparatus and does not incorporate the importance of insertion in local and international markets, a company must become competitive. Operational and administrative efficiency is also a key factor for competitiveness. Porter indicates that a country is competitive based on the performance of its industrial and business sectors.

In this sense, it is understood that the competitiveness of a country depends essentially on the development capacities of the industrial sector to achieve innovation and improvement. A competitive company optimizes its resources to achieve the maximization of productivity, economic and financial benefits and becomes innovative in the insertion of the market and lasts for an important period (Porter, 2021). Other important concepts are an absolute and comparative advantage as well as a competitive advantage. Porter (1998) differentiates these last two concepts, where he clarifies that comparative advantages are inherited, but competitive advantages are created.

There are four spheres of competitiveness: microeconomic, mesoeconomic, macroeconomic, and meta-economic levels (Ramirez and de Aguas, 2017). The microeconomic level refers to the creation of competitive advantages within the company through its management capacity, strategies, and innovation. The mesoeconomic level refers to the efficiency of the environment, the factor market, the physical and institutional infrastructure as well as the specific policies in science, technology, environment, and innovation. It is also known as regional competitiveness. The macroeconomic level corresponds to the fiscal, monetary, commercial, exchange, and budgetary policy, which make it possible to strengthen the industrial apparatus. The fourth level, the meta-economic one, refers to the development-oriented political and economic structure, strategic views, and development plans following the international market (Gutiérrez-Rodríguez and Almanza-Junco, 2016).

Other important concepts about competitiveness and strategy are the forces of competition and the competitive diamond proposed by Porter, which later included the environmental component. In the case of Colombian, the latest reports on national competitiveness involve variables related to state efficiency, justice, corruption, infrastructure, transportation, energy logistics, digital economy, education, health, labor market, pensions, foreign trade, tax system, business finance, science, technology and innovation, green growth, and productivity (CPC, 2021).

Competitiveness variables in the livestock sector. García-García, Figueroa-Rodríguez and Mayett-Moreno (2015), identified key factors associated with competitiveness. Among these are production (productivity or performance), innovation (educational level, technology transfer, cluster), and social factors (quality of housing, politics, income, or phenomena associated with the seasonality of production). The main models and proposals to measure business and sector competitiveness consider the variables mentioned by Sarmiento-Reyes and Delgado-Fernández (2020), which are classified as financial, economic, market, technical, social, environmental.

Among the environmental variables associated with competitiveness is the existence of environmental policies, waste management, and environmental licenses. The key variables associated with competitiveness in the Colombian livestock sector between 1990 and 2010 according to Pertuz-Martínez and Elías-Caro (2019) were low prices in inputs and the dairy sector; supply in the domestic market, increased milk production; genetic crosses suitable for the environment, improved pure breeds, FMD-free meat, dual-purpose cattle, increased areas in the pasture, vertical integration of the meat chain, reduction of production costs, economic labor and incorporation of sustainable livestock production models. Some competitiveness factors, identified by Arredondo-Trapero, Vázquez-Parra and De la Garza (2016), in Latin American countries are innovation, quality of scientific institutions, business investment, academic relationships, business, and government, patents and availability of scientists and engineers.

Sustainability The concept of Sustainable Development SD was mentioned for the first time in the Brundtland Report and its subsequent institutionalization at the Rio Summit was consolidated as one of the philosophical foundations of world environmental policy. The translation of the term sustainable development for the United Nations in Our Common Future (1987), the Rio Declaration (1992), the Kyoto Protocol (1998), the Johannesburg

Summit (2002), the MDGs, and in different articles and citations made is the following: "that development that allows economic growth, increased quality of life and social well-being, without exhausting the base of natural resources, guaranteeing the satisfaction of socioeconomic and environmental needs for the current and future generation".

In environmental economics, Daly (1990) defined sustainable development as the scenario in which the capacity for human exploitation equals the capacity to sustain the environment. Pearce and Turner (1995) establish that the notion of SD could expand the concept of intertemporal efficiency, for a context where some natural resources or resources are not produced by the economic system. In this sense, SD would imply using natural resources in a way that maximizes current production without reducing its future production capacity or maximizing the net benefits of economic development subject to the conservation of natural resources over time.

Among the paradigms of sustainability, there is weak and strong sustainability. The first one establishes that economic well-being can be maintained by substituting natural capital for manufactured capital without exception (Solow, 1997). On the other hand, strong sustainability refers to the substitutability of natural capital, limited by ecological characteristics such as integrity, irreversibility, uncertainty, and the existence of critical components that make a unique contribution to the human being. These views are complementary, since in the first one there is no incompatibility between economic growth and the conservation of natural capital, under the assumption of technological evolution and innovation that allows it, which becomes an anthropocentric approach.

Measurement of sustainability in the rural sector in Latin America. Methods and techniques have emerged for measuring sustainability in the rural sector of Latin America according to López (2012). Some of them are capital analysis, life cycles, multi-criteria decisions, and partial sustainability indicators, among others. These last methods, due to the multidimensional nature of the concept of sustainability, use many qualitative and quantitative variables for their measurement and have been supported by the application of parametric and non-parametric quantitative methods.

Among the first experiences of the assessment of sustainability with indicators specifically directed to the agricultural sector in Latin America, it is possible to identify the document by De Camino and Müller (1993). The authors proposed the integration of variables, complex and dynamic functions involved with the definition of sustainability in an economic system integrated by technology, production and productivity, profitability, resources, population, and their social variables, needs, consumption, and time. Another tool developed for the agricultural sector was the Framework for the Evaluation of Natural Resource Management Systems Using Sustainability Indicators (MESMIS) that begins with a characterization of the production system to determine the strengths and weaknesses, then strategic indicators are selected, implemented, analyzed, and evaluated to recommend improvement actions in the future (Quiroga, 2007).

Other authors such as Cherchye and Kuosmanen (2002) proposed the measurement of sustainable development by calculating the sustainability index through the construction of a frontier by analyzing the data envelopment in which several countries are compared and linked whose economic measurement variables were: the human development index, the poverty index, and a welfare indicator. The socio-political variables were the gender-related development index (GDI), the gender empowerment index (GEM). Similarly, the human well-being index and the environmental variables were the carbon footprint, the ecosystem welfare index, and the environmental sustainability index. This research used the criteria of methodological uniformity among the countries.

Variables associated with sustainability in agricultural systems. Rural productive units are social cells that mesh the dimensions of sustainability and define the development of a country in terms of its food security (Pardo *et al*., 2020). The pressure of these productive systems on natural resources is the high impact due to deforestation, changes in land use, and impacts on ecosystem services. Ecosystem services understood as the processes, raw materials, and energy that nature provides to satisfy the vital needs of living beings, are part of the inventories and potential values that the properties of the Amazonian context have (Constanza *et al*., 1997; Hartwick and Olewiler, 1998). These have been classified as support services, regulation, provisioning, and cultural services.

Supporting services are related to the functioning of ecosystem processes, which creates direct services such as photosynthesis, the formation and storage of organic matter, the cycling of nutrients, the creation and assimilation of the soil, and the neutralization of toxic wastes, among others. Provisioning ecosystem services serve as raw materials, inputs, or energy for direct consumption. Regulation services consist of water, climate, and energy cycles, carbon repositories or sinks, pollination, and oxygen production, among others. Finally, cultural ecosystem services are all those aesthetic, recreational, and cultural values that provide well-being to men, such as scenic beauty, rock pictographs, fossils, virgin forests, and natural landscapes to develop research (Reid, 2005).

In this regard, the ecosystem services immersed in rural production systems in the Amazon are related to natural and environmental resources such as forests, wetlands, surface and underground water bodies, and soil productivity, with all ecosystem products and services. that their interactions involve. Among them are water conservation, biodiversity, pest control, underground water retention, water production, medicinal banks, carbon sinks, erosion reduction, microclimate, environmental corridors, scenic beauty, historical and ancestral values, oil reserves, aquifer recharge zone, species sightings, and soil conservation (Uribe *et al*., 2003; Toledo, Briceño and Ospina, 2018).

Variables associated with competitiveness and rural sustainability. Low agricultural productivity in Colombia limits competitiveness and actions are necessary to accelerate productivity improvements that promote rural development, production chains, sustainable practices, and internationalization (Parra-Peña, Puyana and Yepes-Chica, 2021). The authors mention the following variables for rural competitiveness and sustainability: research, development, and innovation, an environment for the adoption of technology (agricultural extension, education, and training), reforms to factor markets and employment growth non-agricultural in rural areas. Other variables used to measure competitiveness and sustainability in rural areas can be summarized into the following: development indices, quality of life index, index of unsatisfied basic needs (INBI), indicators of governance, index of concentration of income and territory (GINI); efficiency indicators, profitability indicators, ecological footprint, CO2 emissions, biodiversity index, carbon storage levels. These variables are economic, social, political, environmental, and technological.

METHODOLOGY

The study area was the rural area of Belén de Los Andaquíes, Caquetá, located in the Amazon foothills in southern Colombia. The methodological design of this research is quantitative due to the use of statistical techniques (descriptive and inferential) and linear programming and diagnostic tools since the information will be the baseline for the development of other orientations in a practical and theoretical sense (Hernández-Sampieri and Mendoza, 2018). From a population of 300 livestock systems in the study area, a sample of 60 producers was taken using simple random sampling, extracted from the database of the study by Pardo-Rozo (2020), with the values of the variables in Table 1.

Table 1. Description of the product and input variables used in the data envelopment analysis (DEA) to obtain the efficiency frontier of the cattle farms

	VARIABLES OF COMPETITIVENESS AND SUSTAINABILITY OF LIVESTOCK FARMS
***RBC*:**	The variable represents the annual benefit/cost ratio per farm, calculated from the relationship between the present value of income and operating costs for livestock.
***NBS*:**	The variable that represents the number of basic needs satisfied which takes values between 1 and 5, where 5 is a better position than 1.
***CA*:**	Continuous environmental variable, which represents the tons of carbon stored in aerial biomass of the total hectares of forest cover that the farm has.
***NE*:**	The educational level of the entrepreneur or owner. If it does not have any educational level, it takes the value of 1, with the primary level it takes the value of 2, high school 3, technical 4, university 5, and postgraduate 6.
***% BOSQ*:**	Percentage of forest cover present on the farm.
***COSTS*:**	Annual production costs within the farm are measured in Colombian pesos for the year 2021.
***% PTIVO*:**	The relative percentage of productive coverage on the property, the sum of the hectares in Pastures for livestock

Source: Own elaboration.

The methodology presented in Medeiros, Gonçalves-Godoi and Camargo-Teixeira (2019) was used, which used a comparative and econometric analysis of competitiveness, and its determinants are indicated. The data enveloping analysis methodology was used to generate operational efficiency measures associated with competitiveness and sustainability. Then the determinants of competitiveness and sustainability were obtained by using a Tobit model.

Proposal for the construction of an efficiency indicator to determine competitiveness and sustainability. The efficiency frontier (competitiveness and sustainability) was calculated using the DEA with the variables presented in Table 1, where RBC, NBS, and CA act as outputs and the educational level, the percentage of productive soils, forests, and operating costs act as inputs. The indices were calculated according to Coll and Blasco (2006), using the Frontier Analyst program, version 4.4, which yielded efficiency indices between 0 and 1 for each farm. In this research, those farms with a score equal to 1, and with potential towards competitiveness and sustainability when it was less than 1 (inefficient) were considered sustainable, competitive, and sustainable.

The data require a descriptive and inferential analysis according to Gujarati and Porter (2010). The Limdep version 7.0 software was used as a technological tool for statistical analysis. For the determination of competitive and sustainable farms, the Data Envelopment Analysis was used, a linear programming technique that allows the construction of synthetic efficiency indicators from variables with different units. As a linear programming technological tool, the 2018 version Frontier Analyst software will be used. In addition, an econometric model has been presented that attempts to identify the determining factors of sustainability and competitiveness of livestock systems (Gujarati and Porter, 2010).

Mathematical model. Ina similar trend to Pardo-Rozo (2020), the model seeks to solve the problem of maximization of a product and the simultaneous minimization of inputs, through the construction of an optimal production frontier that allows each observation unit to be compared against the estimated optimum. N farms used a certain number of inputs (I) to produce products (P) in a certain period (t). For the i-th farm, the X matrix of order inputs (I x 1) and a Y matrix of order products (P x 1) were taken, both made up of the data observed from the agricultural farms assuming constant returns to scale.

The technical efficiency of a given farm can be estimated through the following linear program, which is expressed in the primal model as Objective function: MaxU, V (Xi, Yi), subject to i) VXi = 1, ii) UYi - VXi ≤ 0, with i = 1,2, … N and U, V ≤ 0; where Xi: represents the inputs of the i-th evaluated cattle farm. Yi represents the products of the i-th evaluated livestock farm. U is a vector of P x 1 optimal products that must be found (the weight of the output). V is a vector of I x 1 the optimal combination of inputs to be found (the weight of the input). The problem is solved by linear programming, by finding the values of U and V that optimize the measure of efficiency (competitive and sustainable for this case) subject to values equal to or less than a unit.

DEA models can be oriented towards supplies (input) or production (output), depending on the existence of constant returns to scale (CCR model) or variable returns (BCC). It should be considered that variable returns can be increasing or decreasing and that it must also be considered whether the inputs can be controlled or not. One of the limitations of the method is that the program can assign a null or scarce weighting to a factor that, from the theory, can be of great importance in the relative efficiency of the productive units (Coll and Blasco, 2006).

Efficiency can be technical, price (or allocative), or global (or economic). It should be taken into account that the DEA provides relative efficiency measures (only concerning its reference set, that is, between the farms in the sample), but does not offer an absolute efficiency measure because it does not compare the DMU against a theoretical maximum, which is to say that the efficiency frontier will be built from the scores of the farms that are closest to meeting the sustainability criteria (economically, politically, socially and environmentally) without be these necessarily sustainable. The inclusion of a new farm with its conditions of inputs and outputs can change all the efficiency scores, defined here as a score towards sustainability.

Tobit model to find the determinants of sustainability. In addition to estimating the sustainability score, a regression model was used to observe the factors on which it depends. The model parameters were obtained from the maximum likelihood estimation method, according to the econometric methodology of Gujarati and Porter (2010), using the Limdep version 7.0 program. The Tobit econometric model was used to observe if the potential for improvement towards sustainability and competitiveness was related to the socio-economic, political, and environmental variables studied. The Tobit model was the most indicated because both the regressive variable and the explanatory variables have censored data (Gujarati and Porter 2010). The Tobit model used was (Equation 1):

$$Not\ efficient = \beta 0 + \beta 1 * Ing + \beta 2 * Bosq + \beta 3 * Past + \beta 4 * Cult + \beta 5 * Bov + \beta 6 * Agri + \beta 7 * Forest + \varepsilon \quad (1).$$

The dependent variable was Not Efficient: it represents the inefficiency indicator according to the coefficients found by the DEA method. This original variable is modified as follows (Gamarra 2004): *Not Efficient* = [1-*Efficient*] / [*Efficient*] information provided by the DEA 1- [$\theta CCR / \theta BCC$], where θ is the score of efficiency with constant returns (CCR) and variable returns (BCC) provided by the DEA model.

The independent variables were: Ing: continuous variable that represents the annual income of the family in Colombian pesos for the year 2020. Bosq: continuous variable that expresses the hectares of forest cover on the farm. Past: continuous variable that expresses the hectares of pasture for livestock that the farm has. Cult: continuous variable that expresses the hectares destined to crops on the farm. Bov: dichotomous variable that takes the value of 1 when the farm develops the economic activity of cattle ranching, otherwise it takes the value of 0. Agri: dichotomous variable that takes the value of 1 when the farm develops commercial agricultural activity, otherwise it takes the value of 0. Forest: dichotomous variable that takes the value of 1 when the farm has rubber or palm crops and develops this economic activity,

RESULTS

Variables of livestock farms associated with competitiveness and sustainability. The variables of competitiveness according to the level of importance given by the producers were grouped into productive capacity, technological capacity, financial capacity, and human talent capacity as internal factors. As external factors, the variables were grouped into access to markets and the perspective of producers in the face of political support for farm productivity, the perception of producers about the support of regional banks to strengthen investment, the conditions of public order, and technology transfer carried out by scientific and academic institutions, which for the region are the el Instituto Amazónico de Investigaciones Científicas SINCHI and the Universidad de la Amazonia respectively.

The internal sustainability variables were grouped into the deforestation carried out on the farm, the importance that livestock producers gave to the potential of the ecosystem services immersed in the properties, land use, and the adoption of sustainable production models or practices. The external factors of sustainability include levels of poverty and the support of the administration and scientific and academic institutions. Table 2 presents the results found for each of these determining variables and associated with competitiveness and sustainability within livestock farms.

Table 2. Variables associated with competitiveness and sustainability in the sample farms

COMPETITIVENESS	UNIT	SUSTAINABILITY	UNIT
INTERNAL FACTORS	(Average)	Internal factors	(value and / or measure)
PRODUCTIVE CAPACITY	4 liters cow day. 24 ha on average per farm	Internal deforestation	58% of farms (0.4 ha yr-1)
FINANCIAL CAPABILITY	$ 15 million annually, with an average cost-benefit ratio of 1.8	Valuation of the ecosystem services of the farm	Null 3%, low 23%, medium 36%, high 38%
TECHNOLOGICAL CAPACITY	5% high, 25% medium, 70% low	Change in land use in 10 years	Null 10%, low 40%, medium 25%, high 25%
HUMAN TALENT CAPACITY	Education level 10% null, 40% primary, 25% high school,	Incorporation of sustainable production models	Null 66%, low 25%, medium 7.8, high 0.2%
		Forest conservation	42% of the farms, 488 trees ha-1.
EXTERNAL FACTORS	(value and / or measure)	External factors	(value and / or measure)
MARKET ACCESS (ROAD VALUATION)	Terrible 34%; Bad 38%; Acceptable 25%, Good 3%	Perception of support in technology transfer for the establishment of sustainable models	Null 43%, low 50%, acceptable 7%
PERCEPTION OF POLITICAL SUPPORT	Null 43%, Very low 52%, Low 5%		

PERCEPTION OF THE FINANCIAL SECTOR	Null 52%, Very low 38%, Low 16% Acceptable 4%	Housing conditions, overcrowding, educational, income level Poverty with more than two UBN unsatisfied basic needs	For the study area, 90% are poor and 10% are in extreme poverty.
PERCEPTION OF PUBLIC ORDER	Acceptable 85%, Good 13%, Excellent 3%		
PERCEPTION OF TECHNOLOGY TRANSFER	Null 43%, Very low 52%, Low 5%		

Source: Own elaboration.

The average monthly income of the households on the farms was considered low because it was less than 1.01 smmlv in 2021. The average value of the CBR for the farms was 1.8, which indicates that each peso disbursed as cost, generated 1.8 pesos of income (maximum value 5 and a minimum of 0.19). The area is characterized by low educational levels for producers. 100% of them have poverty problems associated with low productivity, low income, and access to school for children between 6 and 12 years old. In general, the results indicate the low possibilities of these farms towards competitiveness, since there is no support from the government, the financial sector, and low technological and productive levels are observed, regarding the national production.

In environmental aspects, changes in land use are given from 50% of the productive systems, where 58% carry out deforestation activities. This situation aggravates the conditions to develop a sustainable livestock model since the impact on resources is high. The establishment of sustainable production practices and models is minimal. However, there is a high valuation of the ecosystem services that may be immersed in agricultural properties.

Determination of the efficiency score (Competitiveness and Sustainability). Efficiency scores were found with the variables of competitiveness and sustainability (Table 3).

Table 3. Distribution of efficiency scores (in competitiveness and sustainability) for farms based on product-oriented models with constant-scale yield (CCR) and variable-scale (BCC)

SCORE	EE CCR	%	EE BCC	%
0.4 TO 0.5	1	1.4	1	1.4
0.5 TO 0.6	6	8.5	3	4.2
0.61 TO 0.7	8	11.4	16	22.8
0.71 TO 0.80	31	44.2	25	35.7
0.81 TO 0.9	18	25.7	17	24.2
0.91 TO 0.99	3	4.2	4	5.6
1.00	4	5.6	4	5.6

Source: Own elaboration.

From both approaches (CCR and BCC), it was found that most of the farms of this research obtained an average score between 0.71 to 0.8, followed by a group of farms with scores between 0.81 to 0.9, and only four farms (5.7%) obtained a score of 1 in the four dimensions of sustainability, that is, they generate the sustainability frontier.

Comparison of competitive and sustainable vs. non-efficient farms. The comparison of the competitiveness variables for efficient and inefficient farms is presented below (Table 4). As expected, the competitive and sustainable farms presented higher average values in the variables Carbon stored CA, Ratio Benefit-Cost RBC, Basic Needs Satisfied NBS, Government support AG, and tree density compared to the average of non-competitive and unsustainable farms. For example, the average CA in the sustainable farms was 83.6 t ha-1 compared to the average of 76.4 t ha-1 for the remaining 56 farms.

Table 4. Average values of efficient farms compared to the general average

VARIABLE	4 EFFICIENT FARMS		56 NON-EFFICIENT FARMS	
	Half	**Min - Max**	**Half**	**Min - Max**
RBC	5.0	2.5 - 12.0	4.8	0.2 - 12.8
NBS	4.0	3.0 - 4.0	3.0	2.0 - 4.0
CAT $T\ HA^{-1}$	178.0	166.3 - 293.9	162.47	45.5 - 272.76
PRODUCTIVE LAND (%)	53.0	13 - 91	72.4	0.2 - 98.0
FOREST COVER (%)	13.0	2 - 75	16.9	3.0 - 75.0

Source: Own elaboration.

The percentage of productive land is lower efficient farms than in other farms, a situation that is due to the optimization relationship between the use of land as a factor of production (pastures, crops, and forests). Although the farms that make up the border have technical efficiency scores equal to 1, it does not necessarily indicate that these farms will be competitive and sustainable, but they do stand out from the 60 livestock farms in the study. They were efficient in obtaining carbon, in profitability, with greater basic needs satisfied and the best perception of the support of the government and its policies versus their production costs and productive coverage which is consistent with the criteria of sustainable development: to guarantee economic growth, quality of life, social welfare, and without depleting the natural capital current and future generations.

Identification of key factors associated with the competitiveness and sustainability of livestock farms. A Tobit econometric model was developed in addition to the non-parametric

DEA analysis, which allowed us to analyze the determining variables of the scale efficiency scores. The variables related to the main coverage of the property and the use of the soil in livestock activities (pastures, crops, and forest) were chosen. It was found that the variables that determine the sustainability score were income, hectares in forest, and bovine livestock activity (Table 5). The negative sign of the variable Forest indicates how increasing the hectares in this cover would increase the probability of obtaining a higher score towards efficiency. The opposite case occurred with the variable Income and the variable of livestock activity (cattle), because when income increases, the probability for the Farm to obtain a score towards efficiency decrease. Likewise, livestock farms have a lower probability of efficiency compared to other farms with different economic activities. The information above indicates that livestock activity is not competitive or sustainable, perhaps it is related to the establishment of extensive traditional models that have left low productivity and profitability.

Table 5. Determinants of the efficiency (competitiveness and sustainability) of livestock farms through the Tobit model.

VARIABLE	COEFFICIENT	STANDARD ERROR	P-VALUE	HALF
CONSTANT	-1.17700	0.4720	0.0126	
ENTRY**	0.00038	30.0000	0.0870	763.55
FOREST*	-0.10440	0.0450	0.0120	4.35
PASTURES	-0.00020	0.0050	0.9560	25.00
CROPS	0.04080	0.0360	0.2590	2.81
CATTLE ***	0.64250	0.3935	0.1020	0.72
AGRICULTURAL	-0.07980	0.3045	0.7930	0.23
FOREST	0.09550	0.2943	0.7450	0.43

Source: Own elaboration.

The only statistically significant variable was Forests, which confirms the importance of the Carbon storage ecosystem service for sustainability. In terms of economic activity, only cattle ranching was relevant in the model; the negative sense suggests that the livestock activity is not practiced efficiently.

CONCLUSION

The variables associated with the sectoral competitiveness and sustainability of the cattle farms in the Amazonian foothills were the profitability of the cattle activity, the soils used for this activity, the costs and technological levels of production, the poverty condition of the producers, and the conservation of forests on farms for carbon storage as an important environmental factor against climate change. The variables identified as key factors to study competitiveness in the livestock sector and sustainability were consistent with those proposed in García-García et al. (2015) as well as Pertuz-Martínez and Elías-Caro (2019) which were: the annual income of the farm, the livestock activity, and the forest cover of the farm.

Due to its low profitability, livestock activity is negatively related to competitiveness and sustainability, while the conservation of wooded areas within the farm is positively related to competitiveness and sustainability. This aspect is questionable because this is one of the main culturally introduced socio-economic activities in the region but, due to the fragility of the Amazonian soils, livestock does not correspond to the aptitude for land use. These results, seen from the weak sustainability, allow us to suppose that livestock in the region is negatively affecting the natural and economic resources because all the externalities it causes (deforestation, reduction of carbon sinks, among others) are not compensated by the economic or social system, as shown by the 100% NBI and the assessment of government support and the RBC indicator and the low levels of current production (compared to the national average). Rather, these livestock practices reveal that, in political and institutional terms, an intervention is needed in the economic, productive, and social system, which creates changes in the forms of production and stops the high impacts on the environment and resources, which is more of an approach towards competitiveness.

It was found that the livestock systems in the Colombian Amazonian foothills, in general, are not competitive or sustainable (93%, 56 of the 60 farms). These findings are like the study carried out by Pertuz-Martínez and Elías-Caro (2019) which confirms the last places in competitiveness registered by the departments of the Amazon region in the competitiveness ranking presented by the Consejo Privado de Competitividad (Private Competitiveness Council) in 2020 (26 out of 32). These results are consistent with experiences on the assessment of sustainability and competitiveness in Colombia, including the investigations carried out by Figueroa and Artemio (2016), whose main findings were the dependence of sustainability with economic, ecological, and sociocultural variables. In these studies, the importance of the conservation of ecosystem services in cattle farms in Colombia was highlighted.

Therefore, the measurement of competitiveness and sustainability is multidimensional, and its monitoring allows to foresee factors that determine it and what the efforts should be at the political level. Competitiveness and sustainability are limited by the levels of poverty shown by low education, low technology, and, consequently, low productivity and profitability, minimal possibilities of a family transition to an entrepreneurial class as well as scenarios of ineffective government support to the sector. All these situations decrease the probability of establishing a policy towards sustainable development for the rural sector, despite the comparative advantages that the Amazon foothills have in terms of natural resources, ecosystem services, biodiversity, and food security (Ávila-Foucat, 2017).

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