Revista ARACÊ
ISSN: 2358-2472

ANALYSIS OF ECONOMIC VIABILITY IN A SILVOPASTORAL SYSTEM WITH EMPHASIS ON CARBON NEUTRALIZATION

ANÁLISE DA VIABILIDADE ECONÔMICA EM UM SISTEMA SILVIPASTORIL COM ÊNFASE NA NEUTRALIZAÇÃO DE CARBONO

ANÁLISIS DE LA VIABILIDAD ECONÓMICA EN UN SISTEMA SILVOPASTORAL CON ÉNFASIS EN LA NEUTRALIZACIÓN DEL CARBONO

https://doi.org/10.56238/arev7n9-167

Submission date: 08/15/2025 **Publication date:** 09/15/2025

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ABSTRACT
The development of investment projects is essential for evaluating economic feasibility prior to the implementation of a production system, as it reduces risks and uncertainties in an increasingly competitive market. This study aimed to assess the economic and financial feasibility of a silvopastoral system in the Cerrado Biome, with a focus on sustainable, carbon-neutral beef production. The study sought to demonstrate how integrating trees with livestock farming can support the recovery of degraded areas and compensate for methane emissions resulting from ruminant activity. The proposed scenario included the tree species Tectona grandis (teak), Brachiaria brizantha pasture, and Nelore cattle, implemented over a 1-hectare area across a 20-year horizon. Carbon sequestration and tree volume and diameter were quantified using the SisilpfTeca software. The financial analysis incorporated indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Uniform Annual Equivalent Value (UAEV), Modified Internal Rate of Return (MIRR), among others. Additionally, a Monte Carlo Simulation was employed to evaluate risk and sensitivity. The results indicate that investment is economically viable and that the silvopastoral system contributes to mitigating environmental impacts, promoting soil restoration, animal welfare, water resource conservation, and biodiversity preservation.

Keywords: Carbon Neutrality in Livestock Systems. Environmental Management. Sustainability. Investment Appraisal Techniques.

RESUMO
O desenvolvimento de projetos de investimento é essencial para avaliar a viabilidade econômica antes da implementação de um sistema de produção, pois reduz riscos e incertezas em um mercado cada vez mais competitivo. Este estudo teve como objetivo avaliar a viabilidade econômico-financeira de um sistema silvipastoril no Bioma Cerrado, com foco na produção sustentável e carbono neutro de carne bovina. O estudo buscou

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ISSN: 2358-2472

demonstrar como a integração de árvores com a pecuária pode apoiar a recuperação de áreas degradadas e compensar as emissões de metano resultantes da atividade de ruminantes. O cenário proposto incluiu as espécies arbóreas Tectona grandis (teca), pastagem de Brachiaria brizantha e gado Nelore, implementados em uma área de 1 hectare em um horizonte de 20 anos. O sequestro de carbono e o volume e diâmetro das árvores foram quantificados usando o software SisilpfTeca. A análise financeira incorporou indicadores como Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR), Valor Equivalente Anual Uniforme (VEUA), Taxa Interna de Retorno Modificada (TIRM), entre outros. Além disso, a Simulação de Monte Carlo foi empregada para avaliar risco e sensibilidade. Os resultados indicam que o investimento é economicamente viável e que o sistema silvipastoril contribui para a mitigação dos impactos ambientais, promovendo a restauração do solo, o bem-estar animal, a conservação dos recursos hídricos e a preservação da biodiversidade.

Palavras-chave: Carbono Neutro na Pecuária. Gestão Ambiental. Sustentabilidade. Técnicas de Avaliação de Investimento.

RESUMEN

El desarrollo de proyectos de inversión es esencial para evaluar la viabilidad económica antes de la implementación de un sistema de producción, ya que reduce los riesgos y la incertidumbre en un mercado cada vez más competitivo. Este estudio tuvo como objetivo evaluar la viabilidad económica y financiera de un sistema silvopastoril en el Bioma del Cerrado, con un enfoque en la producción de carne de vacuno sostenible y carbono-neutral. El estudio buscó demostrar cómo la integración de árboles con la ganadería puede contribuir a la recuperación de áreas degradadas y compensar las emisiones de metano derivadas de la actividad rumiante. El escenario propuesto incluyó la especie arbórea Tectona grandis (teca), pasturas de Brachiaria brizantha y ganado Nelore, implementado en un área de 1 hectárea con un horizonte temporal de 20 años. El secuestro de carbono, así como el volumen y diámetro de los árboles, se cuantificaron mediante el software SisilpfTeca. El análisis financiero incorporó indicadores como el Valor Actual Neto (VAN), la Tasa Interna de Retorno (TIR), el Valor Anual Equivalente Uniforme (VAEU) y la Tasa Interna de Retorno Modificada (TIRM), entre otros. Además, se empleó una simulación de Monte Carlo para evaluar el riesgo y la sensibilidad. Los resultados indican que la inversión es económicamente viable y que el sistema silvopastoral contribuye a mitigar los impactos ambientales, promoviendo la restauración del suelo, el bienestar animal, la conservación de los recursos hídricos y la preservación de la biodiversidad.

Palabras clave: Carbono Neutralidad en Sistemas Ganaderos. Gestión Ambiental. Sostenibilidad. Técnicas de Evaluación de Inversiones.

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ISSN: 2358-2472

1 INTRODUCTION

Agribusiness plays a fundamental role in wealth generation in Brazil. To sustain the country's ongoing growth, producers and organizations must adopt innovative approaches grounded in updated knowledge and modern working methodologies (Alves; Costa, 2023).

The Silvopastoral System, also known as the Integrated Livestock-Forest (ILF) System, involves the intentional integration of trees and/or shrubs with native or cultivated pastures, combined with the grazing of ruminants or other herbivores. The primary objective of this integrated model is to combine forestry, pasture, and livestock components, thereby promoting productive diversification through the synergistic use of forest and livestock resources (Carvalho et al., 2003; Da Silva et al., 2011; Embrapa, 2020).

Cattle farming is one of the most prominent sectors of Brazilian livestock production, with Brazil being a global leader in beef exports. Simultaneously, domestic demand for wood has been increasing significantly, with projections indicating that by 2030, the country's demand could reach 300 million m³. Meeting this requirement would necessitate a two- to 2.5-fold expansion of the current planted area (Porfírio-Da-Silva; Moraes; Oliveira, 2014). Therefore, developing projects that integrate timber and livestock production is crucial to address market demands and optimize natural resource use. In addition to generating income from timber and meat, such systems offer financial returns through carbon credit sales, comply with environmental regulations, and contribute to international climate commitments.

2 BIBLIOGRAPHIC REVIEW

2.1 BEEF CATTLE FARMING AND GREENHOUSE GAS EMISSIONS IN BRAZIL

According to SEEG, beef cattle farming accounts for approximately 20% to 25% of Brazil's total greenhouse gas (GHG) emissions, with methane (CH_4) being the predominant gas. This percentage underscores the significant role of cattle farming in national emissions, reflecting its scale and relevance to both the economy and the agricultural sector.

Methane is produced in the digestive tract of ruminants through enteric fermentation. It is estimated that 2% to 12% of the energy consumed by ruminants is converted into CH_4, with variation depending on factors such as diet composition, herd management practices, and individual animal characteristics (Johnson; Johnson, 1995).

Numerous studies have demonstrated that silvopastoral systems are an effective strategy for mitigating CH_4 emissions from cattle. Sarabia-Salgado et al. (2023) report that such systems can reduce emissions by up to 18% compared to conventional grazing systems. This reduction is primarily attributed to improved forage quality, which, when coupled with a more balanced diet, decreases enteric fermentation, the primary source of methane in ruminants.

Additionally, the carbon sequestration capacity of trees, both in their biomass and root systems, serves as an important mechanism for offsetting residual emissions, enhancing the overall environmental benefits of these systems.

2.2 CARBON MARKET

The carbon market is generally divided into two principal frameworks: the regulated market and the voluntary market. Both operate on the basis of carbon credit transactions but differ substantially in their regulatory mechanisms and underlying principles.

The regulated market consists of participants subject to national or international legislation that imposes limitations on GHG emissions. This model is typically aligned with global agreements such as the Kyoto Protocol, which provides the foundational regulatory structure for GHG control. In this context, entities must comply with legal emission caps, and carbon credit trading occurs within this formal framework (Simoni, 2009).

In contrast, the voluntary carbon market (VCM) has emerged independently of regulatory mandates, driven primarily by philanthropic, reputational, or strategic motives. Bayon, Hawn, and Hamilton (2009) cite the case of AES Corporation, which in 1989 implemented an agroforestry project in Guatemala aimed at offsetting its carbon emissions. The company invested in the planting of pine and eucalyptus trees and marketed the carbon credits derived from the project. Notably, this initiative predates the establishment of the regulated carbon market and exemplifies the voluntary nature of early efforts.

Governance represents a central distinction between the two market types. In regulated markets, oversight is conducted by national or international governmental bodies, resulting in a highly structured and controlled environment (Simoni, 2009). In contrast, the voluntary market is characterized by a more decentralized approach, where the parameters of transactions are often defined by the market actors themselves (Bayon; Hawn; Hamilton, 2009).

2.3 ANIMAL WELFARE

Integrated systems such as the ILF offer a viable pathway to enhancing animal welfare, primarily by providing natural shade and improved thermal comfort compared to conventional grazing systems. Glaser (2003) emphasizes that the presence of tree cover significantly reduces heat stress, which is particularly relevant in tropical regions like Brazil, where elevated temperatures can impair homeostasis, the body's capacity to maintain internal equilibrium in the face of external fluctuations.

This physiological stability is governed by interdependent regulatory systems essential to maintaining bodily functions and structural integrity (Brito; Haddad Junior, 2017).

According to the World Organization for Animal Health (OIE, 2019), animal welfare is achieved when animals are healthy, adequately nourished, secure, and free from environmental discomfort. Effective welfare management encompasses temperature regulation, water quality, balanced nutrition, and sufficient space (Baccari, 2001). In the context of cattle, Webster (2005) identifies key welfare indicators including behavioral patterns, physical condition, reproductive performance, and health records. Among these factors, thermal comfort is of particular importance, as it directly affects physiological, behavioral, and productive outcomes. Each species has a thermoneutral zone, defined as the ambient temperature range within which no additional energy expenditure is required to maintain core body temperature (Kadri et al., 2013).

Exposure to temperatures outside this optimal range can lead to heat stress, compromising both animal health and productivity. In beef and dairy cattle, this may result in reduced feed intake, lower productivity, and even infertility (West, 2003). When comparing conventional grazing systems with integrated silvopastoral systems, it becomes evident that the latter provide more favorable conditions for animal development. The synergy of natural shade, moderate ambient temperatures, and ample space enhances animal comfort, health, and productivity.

3 METHODOLOGICAL PROCEDURES

3.1 STUDY AREA

The municipality of Vila Bela da Santíssima Trindade was selected as the study site. It is located in the Southwest mesoregion of the state of Mato Grosso, specifically in the Alto Guaporé microregion, according to the classification of the Brazilian Institute of Geography and Statistics (IBGE, 2008). The municipality is situated between the coordinates 16°15'58.51" and 14°00'20.79" South Latitude and 59°54'19.16" and 60°23'11.64" West Longitude, at approximately 540 km from Cuiabá, the state capital.

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According to the Köppen climate classification system, the region exhibits an equatorial savanna climate (Aw), characterized by a dry winter and an average annual precipitation of approximately 1,500 mm. The climate features a seasonal pattern with six dry months (May to October) and six rainy months (November to April), and annual temperatures range between 25°C and 35°C (IBGE, 2014). Additionally, based on data from the Department of Planning and Economic Affairs (SEPLAN, 2011), the climate is also classified as Tropical Continental, alternating between wet and dry seasons.

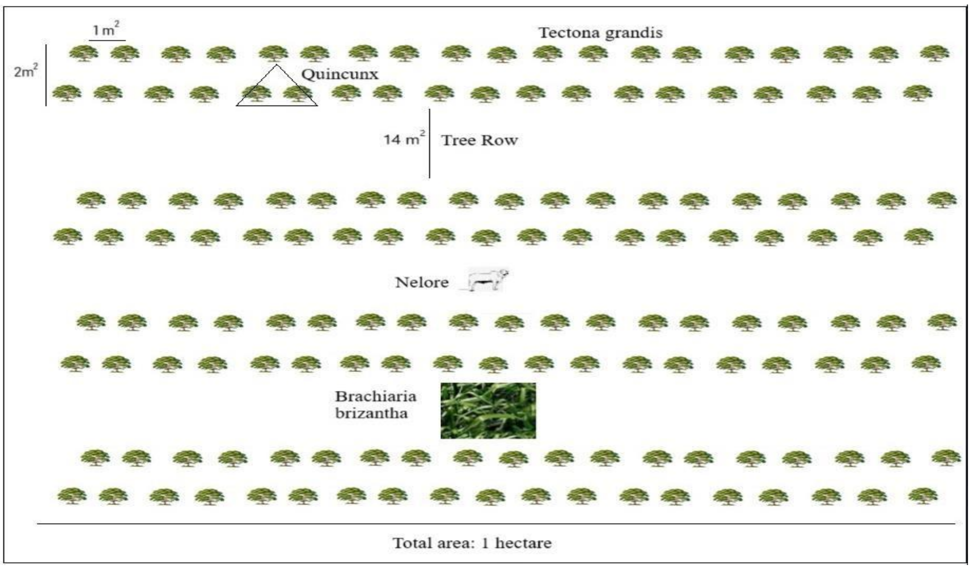
3.2 EVALUATED PLANTING

This study adopted the tree species Tectona grandis, commonly known as teak, which is well adapted to the local climatic conditions. The species was selected due to the favorable environmental conditions in Mato Grosso, its recognized durability, and its high commercial value on the international market, particularly for luxury furniture and shipbuilding applications.

The forest plantation design adopted a double-row spacing configuration of 2x3x2x14 meters in the form of an equilateral triangle. These values refer respectively to the number of rows, the distance between rows within a line, the distance between trees within a row, and the distance between lines of trees. Figure 1 illustrates the spatial arrangement employed in this scenario.

Figure 1

Summary of the Silvopastoral scenario



Source: Prepared by the author (2024).

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The use of tree planting in double rows arranged in an equilateral triangle (quincunx) is a strategic configuration aimed at increasing tree density per hectare. This arrangement ensures more uniform land use, reduces shading on forage crops, and minimizes interspecific competition. Furthermore, it prevents the lateral inclination of tree canopies, thereby promoting balanced and healthy tree development (Behling; Wruck, 2023, p. 399).

This specific spacing pattern, when combined with silvicultural practices such as systematic pruning, leads to yield gains by reducing intra-species competition, lowering establishment and maintenance costs, and enhancing diameter growth (Behling, 2023; Gaafar et al., 2006; Bertomeu, 2012).

In quincunx planting systems with single or double rows, the area between tree rows remains available for pasture, allowing forage species to develop adequately due to regular canopy management. In contrast, triple-row arrangements impede forage growth beneath the canopy, resulting in lost income from livestock activity. This loss must be offset by the increased timber revenue generated by species such as teak (Behling; Wruck, 2023).

Tree density was calculated using a publicly available application developed by the Federal University of Paraná (UFPR) in partnership with Embrapa Forests. The calculated tree number was increased by 20% to account for the triangular planting layout. The final total number of trees included in the scenario was 588 + 117 = 705 trees per hectare. The simulation covered a 20-year planning horizon beginning in 2023. A thinning operation was scheduled for year seven, with final harvesting at year twenty.

3.3 PLANTED FOREST COSTS

To evaluate the economic feasibility of the proposed silvicultural system, average costs related to planting, maintenance, and thinning throughout the teak production cycle were estimated. The analysis excluded harvesting costs and focused on the sale of standing timber.

Implementation costs encompassed activities such as soil preparation (clearing the row, digging, fertilization), ant control, and the acquisition of seedlings and agricultural inputs.

In the first year, maintenance costs were primarily associated with weed and pest control, which are typically higher during establishment. From the second year onwards, maintenance activities included pruning, nutrient management, road maintenance, firebreak construction, fencing, pest control, and annual land leasing costs, all sustained until the final harvest in the twentieth year.

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The land cost estimations were based on the 2023 Land Market Analysis Report (RAMT) for the state of Mato Grosso. The report was jointly prepared by the Ministry of Agrarian Development and Family Farming (MDA), the National Institute for Colonization and Agrarian Reform (INCRA), and the Regional Superintendence of Mato Grosso (SRMT).

The analysis considered the average value of Bare Land Value (VBL) allocated for livestock production in the municipality of Vila Bela da Santíssima Trindade. To cost estimation, the model considered 705 seedlings planted over 1 hectare.

Thinning and final harvest costs were estimated based on prevailing market prices.

According to Technical Note No. 09/2018 from FOMATO (Mato Grosso Forestry Federation), certain taxes and fees are exempt for reforestation initiatives. Consequently, this analysis included only fixed costs and statutory obligations such as the Rural Land Tax (ITR), applied at a rate of 1%, and the applicable income tax rates as defined by the Brazilian Federal Revenue Service.

Depreciation was also calculated as part of the production cost methodology. The procedure followed the guidelines established by Article 305 of the 1999 Income Tax Regulations (RIR/99), which stipulate a ten-year useful life for machinery and equipment used in production. A residual value of 20% was applied in the annual depreciation estimates, based on the projected useful life of the equipment.

3.4 BEEF CATTLE FARMING COSTS

For the livestock farming cash flow, a portion of the data—such as expenditures related to animal health and reproductive management, supplementation, pasture, annual and perennial fodder, fodder conservation, animal acquisition, labor, taxes and fees, maintenance, financial costs, and family labor—was obtained from the 2023 Livestock Market and Production Cost Report published by the Mato Grosso Institute of Agricultural Economics (IMEA).

Additional values, including the bare land value (VBL), were derived from the state's Land Market Analysis Report.

3.5 PLANTED FOREST REVENUE

Following the estimation of costs, the next step involved analyzing the projected revenue from timber sales in years seven and twenty. Revenue projections were based on average annual increment, the number of years until thinning, and the timber price at the time

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of harvest. Thus, timber revenue was calculated as the volume of timber in cubic meters (m^3) multiplied by its unit value (R$/$m^3$).

The price per cubic meter of raw (in natura) timber was obtained from the website of the Mato Grosso State Department of Finance (SEFAZ) and adjusted using the 2023 General Market Price Index (IGPM). The value adopted was R$1,503.20 per m^3. According to local logging companies and producers, this figure is lower than the average market price for traded timber within the state.

Analyses of the silvopastoral system were based on data generated by Embrapa's precision management software, SisilpfTeca. This tool estimates timber volume at various tree ages, allows simulation of thinning interventions, and enables the evaluation of alternative forest management regimes. Additionally, the software estimates accumulated carbon stock and generates classification tables for timber products based on log diameter and length, allocating them to industrial uses such as veneer, sawmill processing, and bioenergy (De Oliveira, 2018).

3.6 CATTLE FARMING REVENUE

Cattle revenue was calculated based on a productivity figure of 5.13 arrobas per hectare, as reported in the profitability bulletin for the state of Mato Grosso. This yield was monetized using the 2023 average arroba price of R$254.69.

3.7 CARBON REVENUE

To estimate the revenue from carbon credits, we adopted the market price listed on the carboncredits.com platform as of September 5, 2023, which quoted a unit value of US$0.8957 per ton of CO_2 equivalent. As the platform lacks a historical pricing series, the 2023 price was retroactively estimated by applying the reported -62.64% year-over-year variation from September 5, 2024. The average exchange rate for the US dollar in 2023, R$4.99, was used to convert the value into Brazilian Reais (R$).

The formula used by the software to calculate tons of CO_2 was as follows:

tCO2 from Volume = (Volume)x(Basic Density: 0.35) x Carbon Fraction (C: 0.49) x CO_2 Conversion Factor (3.66)

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The carbon cash flow considered only the CO_2 sequestered by the 705 trees included in the forest component of the system. Carbon sequestration from other system elements - such as forage and litter - was not included.

Given that one of the objectives of this study was to demonstrate that the livestock–forest integration model can fully offset methane (CH_4) emissions from an extensive grazing system, CH_4 emissions were deducted from the projected carbon revenue. To perform this calculation, CH_4 was converted into its CO_2 equivalent, enabling subtraction of livestock emissions from the total carbon credits generated. Table 1 presents the converted CH_4 values and the corresponding CO_2 offset calculations.

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Table 1

Carbon conversion and offsetting

	YEAR																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ton of CO2e	**0**	**1.2**	**5.2**	**11**	**17.6**	**24.2**	**30.4**	**28.9**	**37.6**	**46.2**	**54.4**	**62.3**	**69.9**	**77.1**	**83.9**	**90.5**	**96.6**	**102.5**	**108**	**113.3**
CO2e (kg)	0	1200	5200	11000	17600	24200	30400	28900	37600	46200	54400	62300	69900	77100	83900	90500	96600	102500	108000	113300
Methane emissions from 5.13 @ converted to CO_2e (kg)	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09	528.09
Net carbon sequestration (after emissions offset)	-528.09	671.91	4,671.91	10,471.91	17,071.91	23,671.91	29,871.91	28,371.91	37,071.91	45,671.91	53,871.91	61,771.91	69,371.91	76,571.91	83,371.91	89,971.91	96,071.91	101,971.91	107,471.91	112,771.9
Ton of CO2e after offsetting emissions	-0.53	0.67	4.67	10.47	17.07	23.67	29.87	28.37	37.07	45.67	53.87	61.77	69.37	76.57	83.37	89.97	96.07	101.97	107.47	112.77

Source: Prepared by the author (2024).

Only the remaining carbon credit value - after accounting for methane emissions from the livestock unit - was included in the final cash flow. Specifically, CH_4 emissions were calculated based on a productivity of 5.13 arrobas per hectare. It was assumed that a steer raised under a silvopastoral system, with a final weight of 17 arrobas, produces approximately 70 kg of CH_4 per year.

3.8 ECONOMIC EVALUATION CRITERIA

Based on the estimated costs and revenues from reforestation, cattle farming, and carbon sequestration, an economic evaluation was conducted using a range of investment appraisal techniques. These included: Net Present Value (NPV), Internal Rate of Return (IRR), Uniform Annual Equivalent Value (UAEV), Discounted Payback Period (PBd), Profitability Index (PI), Modified Internal Rate of Return (MIRR), Benefit/Cost Ratio (B/C), the Capital Asset Pricing Model (CAPM), as well as sensitivity and risk analysis using Monte Carlo Simulation. The Net Present Value (NPV) represents the present value of future cash flows discounted at a given rate and serves as a key criterion for investment decision-making. A higher NPV denotes greater project attractiveness (Assaf, 2010). The NPV is calculated using the following formula:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+K)^t} - I_0 + \sum_{t=1}^{n} \frac{I_t}{(1+K)^t} \quad (1)$$

Where:

= cash flow at time t;

K = discount rate (minimum required rate of return);

I0 = initial investment at time zero;

It = investments in subsequent periods.

The Internal Rate of Return (IRR) must exceed the Minimum Attractiveness Rate (MAR) for a project to be considered viable. The IRR is the discount rate that equates the present value of expected inflows with the present value of investments (Assaf, 2010). If IRR < MAR, the project is considered financially unviable (Drozdowski, 2022). The IRR is defined as:

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$$IRR = I_0 + \sum_{t=1}^{n} \frac{I_t}{(1+k)^t} - I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} \quad (2)$$

Where:

I0 = initial investment;

It = investment in period t;

K = periodic equivalent annual rate of return (IRR);

CF = expected cash inflows.

The Discounted Payback Period (PBd) measures the time required to recover the initial investment, considering the time value of money (Laponi, 2000).

The equation used to calculate the DP is given by:

$$Discounted\ Payback = minimum\ \{j\} \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} \geq CF_0 \quad (3)$$

Where:

= project cash flow at time t;

k = the project's discount rate, represented by the minimum required return or MAR;

CF0 = the project's cash flow at time 0.

The Profitability Index (PI) is the ratio of the present value of cash inflows to the present value of investments, indicating the value created per unit of investment (Ross, 1995). It is given by:

$$PI = \frac{\sum_{t=1}^{n} \frac{CF_t}{(1+k)^t}}{inv} \quad (4)$$

Where:

CFt = cash flow at time t;

k = cost of capital or MAR;

n = number of periods analyzed;

t = period analyzed;

inv = initial investment, which corresponds to the cash flows at date zero.

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The Modified Internal Rate of Return (MIRR) is a refinement of the IRR that accounts for reinvestment assumptions and cost of capital. It modifies the cash flows before calculating the return, offering a more realistic measure of project performance (Ross et al., 2013). The MIRR is expressed as:

$$MIRR = \left(\frac{\sum_{t=0}^{n} Y_t * (1+k_1)^{n-t}}{\sum_{t=0}^{n} C_t * (1+k_2)^{-t}}\right)^{\frac{1}{n}} - 1 \qquad (5)$$

Where:

Yt = Positive cash flow in period t;
Ct = Negative cash flow in period t;
N = total number of periods;
k1 = reinvestment rate;
k2 = financing cost.

Sensitivity and Risk Analysis helps identify key variables that significantly affect project outcomes. The Net Present Value (NPV) is particularly sensitive to uncertain variables such as market prices, yields, pest outbreaks, and climatic extremes. These uncertainties were addressed using Monte Carlo Simulation, which allows for probabilistic modeling of input variables and their effect on financial metrics (Ross et al., 2013).

The Benefit/Cost Ratio (B/C) establishes the relationship between the present value of benefits and the present value of costs. Projects are considered economically viable when the B/C ratio exceeds 1, indicating that benefits outweigh costs (Vitale; Miranda, 2010). The ratio is computed as:

$$B/C = \frac{VB(k)}{VC(k)} \qquad (6)$$

Where:

B/C = Benefit/Cost ratio;
VB (k) = discounted value of benefits at rate k; and

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ISSN: 2358-2472

VC (k) = discounted value of costs at rate k.

To determine the Minimum Attractiveness Rate (MAR) or opportunity cost of capital, the Capital Asset Pricing Model (CAPM) was applied. The CAPM has been widely validated and expanded through models such as the Godfrey-Espinosa (1996), Lessard (1996), Goldman-Sachs–Mariscal–Hargis (1999), Damodaran (2002), Assaf Neto (2008), and the L-CAPM, AL-CAPM, and AH-CAPM developed by Pereiro (2001) (Martinelli, 2018). The CAPM is given by:

$$K_e = R_f + \beta\,(R_m - R_f) + E \qquad (7)$$

Where:

Ke - Cost of equity or minimum attractiveness rate;
Rf - Risk-free rate; β - beta coefficient (systematic risk);
Rm - expected market return.

Finally, the gross sales revenue of the project was estimated using the following equation:

$$R(x) = p(x)\ x\ q(x) \qquad (8)$$

Where:

R(x) = gross sales revenue.
p(x) = market price of the product.
q(x) = quantity produced.

4 RESULTS AND DISCUSSION

Table 2 presents a comprehensive overview of the revenues and expenditures associated with the silvopastoral system evaluated, which integrates livestock production, timber harvesting, and carbon credit generation. This table outlines the cash flow over a 20-year horizon, illustrating the progression of income streams alongside operational and Investment costs.

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Table 2

Complete and Detailed Cash Flows

Scenario Cash Flow																			
Description		1. Gross Sales Revenue	1.1 Gross Revenue - Livestock Farming	1.2 Gross Revenue - Timber	1.3 Gross Revenue – Carbon Credits	2. Revenue Deductions	3. Net Sales Revenue	4. Production Costs	4.1 Production Costs - Livestock Farming	4.2 Production Costs - Timber	5. Operating Profit	6. Income Tax	7. Net Operating Profit	8. Depreciation	9. Operating Cash Flow	10. Total Investment	10.1 Fixed Investment	10.2 Working Capital Investment	Free Cash Flow
	0															(10,754.30)	(2,492.82)	(8,261.48)	(10,754.30)
	1	1,308.93	1,306.56	-	2.37	1.58	1,307.35	1,590.46	1,093.87	496.59	(283.11)	-	(283.11)	138.13	(144.98)				(144.98)
	2	1,309.55	1,306.56	-	2.99	1.58	1,307.97	1,590.46	1,093.87	496.59	(282.49)	-	(282.49)	138.13	(144.36)				(144.36)
	3	1,327.43	1,306.56	-	20.87	1.58	1,325.85	1,590.46	1,093.87	496.59	(264.61)	-	(264.61)	138.13	(126.48)				(126.48)
	4	1,353.36	1,306.56	-	46.80	1.58	1,351.78	1,386.00	1,093.87	292.13	(34.22)	-	(34.22)	138.13	103.91				103.91
	5	1,382.86	1,306.56	-	76.30	1.58	1,381.28	1,386.00	1,093.87	292.13	(4.72)	-	(4.72)	138.13	133.41				133.41
	6	1,412.36	1,306.56	-	105.80	1.58	1,410.78	1,386.00	1,093.87	292.13	24.78	-	24.78	138.13	162.91				162.91
	7	25,791.92	1,306.56	24,351.84	133.52	4,141.39	21,650.53	1,386.00	1,093.87	292.13	20,264.53	1,114.55	19,149.98	138.13	19,288.11				19,288.11
	8	1,433.37	1,306.56	-	126.81	1.58	1,431.79	1,386.00	1,093.87	292.13	45.79	-	45.79	138.13	183.92				183.92
	9	1,472.26	1,306.56	-	165.70	1.58	1,470.68	1,386.00	1,093.87	292.13	84.68	-	84.68	138.13	222.81				222.81
	10	1,510.70	1,306.56	-	204.14	1.58	1,509.12	1,386.00	1,093.87	292.13	123.12	-	123.12	138.13	261.25				261.25
	11	1,547.36	1,306.56	-	240.80	1.58	1,545.78	1,386.00	1,093.87	292.13	159.78	-	159.78	138.13	297.91				297.91
	12	1,582.67	1,306.56	-	276.11	1.58	1,581.09	1,386.00	1,093.87	292.13	195.09	-	195.09	138.13	333.22				333.22
	13	1,616.64	1,306.56	-	310.08	1.58	1,615.06	1,386.00	1,093.87	292.13	229.06	-	229.06	138.13	367.19				367.19
Years	14	1,648.83	1,306.56	-	342.27	1.58	1,647.25	1,386.00	1,093.87	292.13	261.25	-	261.25	138.13	399.38				399.38

15	1,679.22	1,306.56	-	372.66	1.58	1,677.64	1,386.00	1,093.87	292.13	291.64	-	291.64	138.13	429.77		429.77
16	1,708.73	1,306.56	-	402.17	1.58	1,707.15	1,386.00	1,093.87	292.13	321.15	-	321.15	138.13	459.28		459.28
17	1,735.99	1,306.56	-	429.43	1.58	1,734.41	1,386.00	1,093.87	292.13	348.41	-	348.41	138.13	486.54		486.54
18	1,762.37	1,306.56	-	455.81	1.58	1,760.79	1,386.00	1,093.87	292.13	374.79	-	374.79	138.13	512.92		512.92
19	1,786.95	1,306.56	-	480.39	1.58	1,785.37	1,386.00	1,093.87	292.13	399.37	-	399.37	138.13	537.50		537.50
20	272,987.92	1,306.56	271,177.28	504.08	46,101.72	226,886.20	1,386.00	1,093.87	292.13	225,500.20	12,402.51	213,097.69	138.13	213,235.82	8,261.48	221,497.30

Source: Prepared by the author, survey data (2024).

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Livestock production yields a stable annual income throughout the 20-year period, with an average of approximately R$1,306.56 per year. Timber revenues become significant starting in year 7, following the thinning of 299 trees within the system. The final harvest occurs in year 20, at which point cash flow reaches its maximum. Carbon revenue begins contributing from the second year onward, reflecting the sale of carbon credits generated by tree biomass, in excess of the amount required to offset methane (CH_4) emissions from cattle.

Production costs are distributed between the livestock and forestry components. Livestock-related costs remain relatively constant at around R$1,093.87 per year, covering operational and animal management expenses. In contrast, forestry costs vary over time, being highest during the early years due to establishment and silvicultural management and declining as the system approaches the harvesting stage.

Operating profit - calculated as the difference between net revenue and production costs - becomes positive from the fifth year and increases thereafter. This positive trend is primarily driven by escalating revenues from timber and carbon credits, which intensify in later years.

Capital expenditures, both fixed and working capital, are concentrated in the early years of the project, reflecting the initial implementation costs of the silvopastoral system. As livestock production stabilizes and forestry and carbon revenues commence, free cash flow becomes positive by the fourth year and continues to grow steadily through the end of the projection, culminating in R$221,497.30 by year 20.

The system's economic viability is reinforced by revenue diversification and the environmental co-benefits of carbon sequestration. The data confirm that, from year 6 onward, the project reaches financial equilibrium, with sustained profitability and positive net cash flow. These findings indicate that the silvopastoral model constitutes a viable long-term strategy, enhancing livestock productivity while contributing to environmental conservation through greenhouse gas mitigation.

The integration of trees within pastureland serves not only to reduce CH_4 emissions but also provides significant additional revenue from timber and carbon markets. Using the cash flow data from years 1 to 20, the Internal Rate of Return (IRR) was calculated to be 20.49% annually. By comparison, the Minimum Attractiveness Rate (MAR), estimated using the Capital Asset Pricing Model (CAPM), was determined to be 11.11%. Given that the IRR exceeds the MAR, the project is considered financially attractive.

For the CAPM calculation, this study utilized the following data sources:

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(1) The average yield on 30-year Treasury Bonds from 2014 to 2023 (10 years) from data available at: https://br.investing.com/rates-bonds/usa-government-bonds?maturity_from=40&maturity_to=290 ttps://www.treasury.gov.

(2) The unlevered beta coefficient for the Farming/Agriculture sector based on data available at: https://pages.stern.nyu.edu/~adamodar/.

(3) The average yield of the Standard & Poors 500 index from 2014 to 2023 (10 years) based on data available at: https://www.slickcharts.com/sp500/returns.

(4) Average country risk rate measured by the EMBI+ index from 2014 to 2023 (10 years) based on data available at: http://www.ipeadata.gov.br/Default.aspx.

(5) Estimated average inflation rate for the American economy from 2024 to 2029 based on data available at: https://www.statista.com/statistics/244983/projected-inflation-rate-in- the-united-states/.

Table 3

Calculation of the Cost of Equity Using the CAPM Model Items

Items

Items	Values
U.S. Treasury Bonds (1)	2.81%
Beta coefficient – Agriculture Sector (2)	0.74
S&P 500 Average Return (3)	13.13%
Country Risk Premium – EMBI+ (4)	2.88%
Projected U.S. Inflation Rate (5)	2.22%
Cost of Equity – *Ke* (Global CAPM Benchmarking Model, Real Rate)	11.11%

Source: Prepared by the author (2025).

4.1 ANALYSIS OF ECONOMIC AND FINANCIAL FEASIBILITY

Table 4 shows the project’s economic viability and financial sustainability based on key financial indicators.

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Table 4

Results of investment appraisal techniques

Investment appraisal techniques	Values
IRR	20.49%
NPV	R$ 26,285.31
UAEV	R$ 3,324.57
PI	R$ 3.44
B/C	R$ 4.21
PBd	5.81
MIRR	18.03%

Source: Prepared by the author (2025).

An Internal Rate of Return (IRR) of 20.49% reflects a return substantially above the estimated cost of equity of 11.11%. This result underscores the project's financial attractiveness, exceeding risk-adjusted profitability thresholds, a critical consideration for long-term investments. When compared to the Minimum Attractiveness Rate (MAR), which represents the opportunity cost of investing in lower-risk alternatives, the IRR suggests that this project offers robust and competitive returns.

The Net Present Value (NPV) of R$26,285.31 further confirms the project's feasibility, indicating a positive financial surplus. This surplus signifies that, when discounted at the cost of capital, the cash flows generated by the project surpass the initial investment, thereby creating additional economic value. In practical terms, this means the anticipated revenues considerably outweigh associated costs and risks, reinforcing the recommendation for project implementation.

The Uniform Annual Equivalent Value (UAEV) of R$3,324.57 converts the NPV into an annualized metric, providing insight into the average yearly returns the project would yield over its operational lifespan. This annual measure is especially relevant for long-duration projects, as it facilitates an understanding of long-term performance through a consistent cash flow stream. The positive UAEV demonstrates the project’s capacity to generate stable and significant returns annually, enhancing its financial resilience.

The Profitability Index (PI) of 3.44 and the Benefit-Cost Ratio (B/C) of 4.21 emphasize the project’s efficiency in capital utilization. These figures indicate that for every R$1 invested, the project generates between R$3.44 and R$4.21 in returns, evidence of an excellent return on capital. Both indicators confirm the project’s economic sustainability and capacity to deliver substantial net benefits.

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The Discounted Payback Period (PBd) of 5.81 years represents the time required to recover the initial investment, adjusted for the time value of money. This relatively short payback period, in the context of a 20-year project horizon, suggests a favorable risk profile, as the initial capital is recovered early in the investment cycle, offering greater security for investors. Achieving payback within this timeframe demonstrates solid financial resilience, even under fluctuating economic conditions.

The Modified Internal Rate of Return (MIRR), estimated at 18.03%, adjusts the IRR to account for a more conservative reinvestment rate. This adjustment provides a more realistic representation of the effective return, particularly in scenarios where intermediate cash flows are not reinvested at the original rate. For this calculation, an interest rate of 3% was applied, corresponding to investment credit lines under the National Program for Strengthening Family Farming (Pronaf), specifically Pronaf Forest. This conservative assumption enhances the prudence of financial assessment.

Overall, the results confirm the economic feasibility and profitability of the proposed silvopastoral project. The elevated IRR and NPV highlight the project's capacity to deliver strong returns relative to the assumed risk level. Concurrently, the UAEV and PI reinforce the project's capacity to generate annual financial gains and ensure the efficient allocation of invested capital. The PBd offers additional assurance by indicating early cost recovery, thereby reducing exposure to long-term financial risk.

Moreover, the MIRR, adjusted for a modest reinvestment rate, demonstrates that the project remains financially attractive even under conservative assumptions. This cautious interpretation of the financial indicators strengthens confidence in the project's viability and supports informed decision-making, even under scenarios of moderate return volatility.

4.2 MONTE CARLO SIMULATION

Monte Carlo Simulation enables a probabilistic analysis of outcomes by performing thousands of iterations based on random variations of input variables (Metropolis; Ulam, 1949). This method is instrumental in evaluating financial robustness and risk exposure, providing insights into the probability distribution of project outcomes under diverse scenarios. Figure 2 illustrates the variability of NPV when subjected to Monte Carlo Simulation, where multiple variables are simultaneously randomized.

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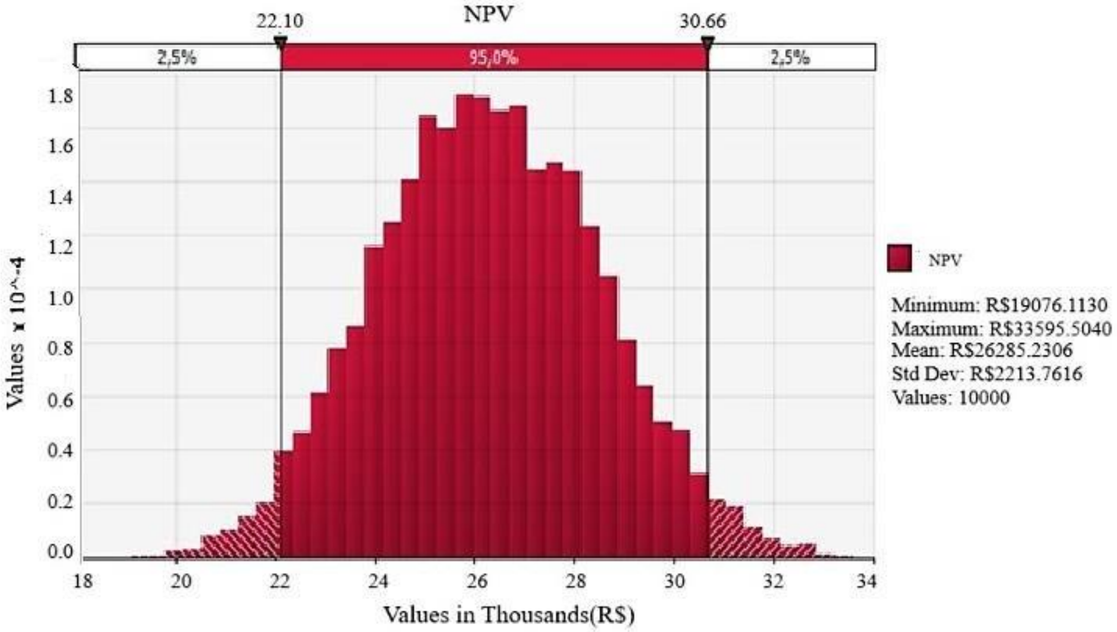
Figure 2

Monte Carlo simulation of cash flow NPV



Source: Prepared by the author (2024).

The simulation produces a probability distribution for the NPV, allowing identification of the most likely outcome ranges and supporting a comprehensive assessment of project risk and return. This approach is widely applied in financial and operational analyses to capture uncertainty and generate confidence intervals for key metrics (Hertz, 1964). The symmetrical distribution in Figure 6 affirms the model's ability to convey the potential variability in returns, aiding in the identification of volatility boundaries.

In this case, a 95% confidence interval ranging from R$22,100 to R$30,660 suggests a moderate risk profile with low probability of extreme losses. This distribution enhances the credibility of the financial projections and affirms the project's capacity to withstand fluctuating conditions.

Savage (2003) builds on Hertz's framework by emphasizing that Monte Carlo Simulation addresses a major shortcoming in conventional decision-making: the tendency to overlook the variability of potential outcomes. The graphical representation in Figure 6 replaces a single deterministic NPV estimate with a probabilistic distribution, thereby offering a more nuanced understanding of project performance. The simulation yielded a mean NPV of R$26,285.23, with a standard deviation of R$2,213.76, reflecting the expected fluctuation around the central estimate.

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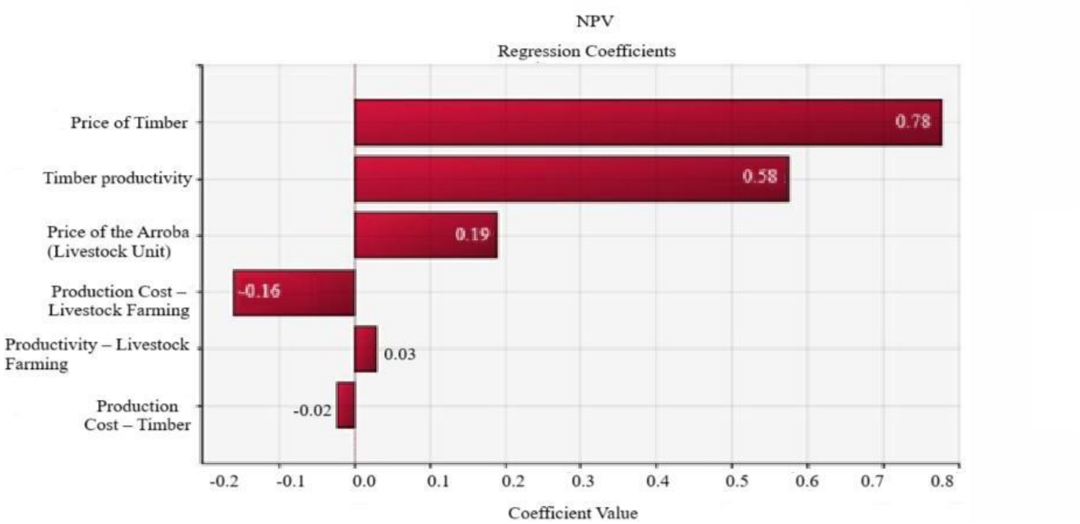
By incorporating the variability of inputs and their probabilistic interactions, Monte Carlo Simulation enhances decision-making under uncertainty. It enables stakeholders to consider a range of potential outcomes and associated risks, thereby facilitating more robust and informed investment planning (Savage, 2003).

4.3 SENSITIVITY ANALYSIS

The graph presented in Figure 3 illustrates the regression coefficients derived from the Monte Carlo simulation applied to the Net Present Value (NPV). It reveals the influence of various input variables on the simulation outcomes, highlighting both positive and negative effects. A detailed analysis is provided below:

Figure 3

Price sensitivity analysis



Source: Prepared by the author (2024).

4.3.1 Key variables with positive impact

The timber price exerts the most significant positive influence on the NPV. Increases in timber prices result in substantial financial gains, demonstrating the central role of the forestry component in the system's economic performance. This finding underscores the importance of implementing effective marketing strategies to secure favorable timber prices.

Timber productivity also contributes notably to the NPV. Enhancements in productivity - achieved through improved silvicultural practices, thinning, and harvesting

-have a strong positive correlation with project profitability, highlighting the value of technical efficiency in forest management.

Although less influential, the price of the arroba (a unit of beef weight) still contributes positively to the NPV. This indicates that, despite its smaller relative impact compared to timber, the livestock component adds economic value to the integrated system.

4.3.2 Variables with negative impact

Livestock farming costs represent the most influential negative variable. Increases in these costs directly reduce the NPV, emphasizing the critical need for stringent expense control and efficiency in livestock operations.

The cost of timber production, while also having a negative impact, is nearly negligible. This suggests that operational expenses in forestry do not substantially erode the financial benefits derived from timber revenue.

4.3.3 Main observations

1. Relevance of timber production: The system's financial viability is heavily dependent on both the price and productivity of timber. Optimizing these factors can significantly enhance economic returns.
2. Livestock cost management: Effective cost control in cattle farming is vital, as rising operational costs diminish profitability.
3. Limited contribution from livestock revenues: In terms of price and productivity, the livestock component has a relatively small effect on overall project returns. This suggests that, while livestock is important, the economic focus should remain on timber production to maximize gains.
4. Forestry as the primary economic driver: The results affirm that the forestry component is the main engine of financial performance within the system. Livestock plays a complementary role and must be managed efficiently to avoid undermining overall returns.
5. According to Savage (2003), the use of probabilistic simulation techniques—such as Monte Carlo Simulation—enhances decision-making by addressing the common tendency to underestimate risks in complex planning scenarios.

5 CONCLUSIONS

In conclusion, the financial analyses confirm that the proposed silvopastoral system is both economically viable and profitable, offering stable returns with a relatively low investment risk. The financial indicators support a favorable investment decision, demonstrating that the project meets the profitability and security thresholds typically required for sustainable long-term investments.

The results presented in Tables 6 and 7, when combined with carbon mitigation data, reinforce the dual environmental and economic viability of the system. The integration of livestock and forestry components allows not only the recovery of degraded lands and carbon sequestration but also the monetization of these ecosystem services through carbon credit markets

Monte Carlo Simulation proved to be a vital tool in assessing the financial feasibility and risk exposure of the project. The results show that the NPV falls within a 95% confidence interval ranging from R$22,100 to R$30,660, with an average estimated NPV of R$26,285.23 and a standard deviation of R$2,213.76. These figures reflect the project's financial robustness and the value of incorporating probabilistic methodologies to address uncertainty.

Additionally, the sensitivity analysis identified timber-related variables, particularly price and productivity, as the main drivers of economic performance. Conversely, livestock costs emerged as the principal source of negative impact, reaffirming the need for operational efficiency and cost management in cattle production.

By combining probabilistic simulations with sensitivity analysis, this study successfully identified the critical factors determining the project's financial success. These tools provided a sound analytical basis for strategic planning and supported more informed decision-making, especially in complex, uncertain, and dynamic contexts typical of integrated agroforestry systems.

REFERENCES

Alves, N. A., & Costa, J. G. (2023). Demanda por carnes no Brasil: Uma análise do consumo das famílias brasileiras entre 1970 e 2022. Economia Regional, Londrina, 11(3), 405–423. https://doi.org/10.5433/2317-627X.2023.v11.n3.47297

Assaf Neto, A. (2010). Matemática financeira e suas aplicações (2nd ed.). Atlas.

Bäckstrand, K., & Lövbrand, E. (2016). The road to Paris: Contending climate governance discourses in the post-Copenhagen era. Journal of Environmental Policy & Planning, 18(5), 1–19. https://www.researchgate.net/publication/297727326_The_Road_to_Paris_Contending_Climate_Governance_Discourses_in_the_Post-Copenhagen_Era

Baccari Júnior, F. (2001). Manejo ambiental da vaca leiteira em climas quentes (Vol. 138). UEL.

Behling, M., & Wruck, F. J. (2023). Sistemas de integração teca (Tectona grandis L. f.) em ILPF. In C. M. dos Reis, E. B. de Oliveira, & A. J. dos Santos (Eds.), Teca (Tectona grandis L. f.) no Brasil (pp. 399–403). Embrapa Florestas.

Brito, I., & Haddad, J. H. (2017). A formulação do conceito de homeostase por Walter Cannon. Filosofia e História da Biologia, 12(1), 99–113. http://www.abfhib.org/FHB/FHB-12-1/FHB-12-01-06-Ivana-Brito_Hamilton-Haddad.pdf

Carvalho, M. M., & et al. (2003). Sistemas silvipastoris na recuperação de pastagens degradadas. Embrapa. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/43967/1/005C.pdf

Código Terrestre de Saúde Animal. (2017). Introdução às recomendações para bem-estar animal (Ministério da Agricultura, Pecuária e Abastecimento, Trans.). https://www.oie.int

Da Silva, J. L. S., & et al. (2011). Manejo de animais e pastagens em sistemas de integração silvipastoril (Documentos, 335). Embrapa Clima Temperado. https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/952812/1/documento335.pdf

De Oliveira, E. B., Porfírio-da-Silva, V., & Ribaski, J. (2018). SisILPF – Software para simulação do crescimento, produção, metano e manejo do componente florestal em sistemas de integração lavoura-pecuária-floresta.

De Souza, N. R. D., & et al. (2019). Sugarcane ethanol and beef cattle integration in Brazil. Biomass and Bioenergy. https://doi.org/10.1016/j.biombioe.2018.12.012

Embrapa. (2020). Presença de árvores melhora qualidade da pastagem. https://www.embrapa.br/agencia-de-noticias-embrapa/busca-de-noticias/-/noticia/81415706/presenca-de-arvores-melhora-qualidade-da-pastagem

Galvão, M. C. B., & Ricarte, I. L. M. (2019). Revisão sistemática da literatura: Conceituação, produção e publicação. Logeion: Filosofia da Informação, 6(1), 57–73.

Ganz, A. C. S., Schlotefeldt, J. O., & Rodrigues Junior, M. M. (2020). Corporate governance and capital asset pricing models. RAM. Revista de Administração Mackenzie, 21(2), Article eRAMF200010.

Glaser, F. D. (2003). Aspectos comportamentais de bovinos da raça Angus a pasto frente à disponibilidade de recursos de sombra e água para imersão [Master's dissertation, Universidade de São Paulo].

Revista ARACÊ
ISSN: 2358-2472

Hertz, D. B. (1964). Risk analysis in capital investment. Harvard Business Review, 42, 95–106.

Johnson, K. A., & Johnson, D. E. (1995). Methane emissions from cattle. Journal of Animal Science, 73(8), 2483–2492.

Köppen, W., & Geiger, R. (1928). Klimate der Erde. Verlag Justus Perthes.

Martinelli, G. do C., & et al. (2018). Sistemas agroflorestais biodiversos: Uma análise sob a perspectiva ambiental e econômica [Doctoral dissertation, Universidade Federal da Grande Dourados].

Metropolis, N., & Ulam, S. (1949). The Monte Carlo method. Journal of the American Statistical Association, 44(247), 335–341.

Nair, P. K. R., & et al. (2011). Silvopasture and carbon sequestration with special reference to the Brazilian savanna (Cerrado). In Carbon sequestration potential of agroforestry systems: Opportunities and challenges (pp. 145–162).

Organização Mundial da Saúde Animal. (2019). Código sanitário para os animais terrestres. https://www.oie.int

Porfírio-da-Silva, V., Moraes, E., & de Oliveira, E. B. (2014). Integração lavoura-pecuária-florestas na cadeia produtiva da madeira. In Embrapa (pp. 257–276). https://ainfo.cnptia.embrapa.br/digital/bitstream/item/117599/1/2014-AAC-Porfirio-Integracao.pdf

Rodrigues, L. M. S., & Marta-Costa, A. A. (2021). Competitividade das exportações de carne bovina do Brasil: Uma análise das vantagens comparativas. Revista de Economia e Sociologia Rural, 59(1), Article e238883.

Ross, S. A., & et al. (2013). Fundamentos de administração financeira (L. Zilio & R. G. Barbosa, Trans., 9th ed.). Amgh.

Savage, S. L., & Markowitz, H. M. (2009). The flaw of averages: Why we underestimate risk in the face of uncertainty. John Wiley & Sons.

Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: A best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. Annual Review of Psychology, 70(1), 747–770.

Silva, F. L., & et al. (2022). Trace elements in beef cattle: A review of the scientific approach from one health perspective. Animals, 12(17), Article 2254.

Vitale, V., & Miranda, G. de M. (2010). Análise comparativa da viabilidade econômica de plantios de Pinus taeda e Eucalyptus dunnii na região centro-sul do Paraná. Revista Floresta, 40(3), 469–476.

Revista ARACÊ
ISSN: 2358-2472

Webster, J. (2005). The assessment and implementation of animal welfare: Theory into practice. Revue Scientifique et Technique-Office International des Epizooties, 24(2), 723.

West, J. W. (2003). Effects of heat-stress on production in dairy cattle. Journal of Dairy Science, 86(6), 2131–2144.