Article

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça[1] [ID], **Luiz Fernando de Sousa Antunes[2]** [ID], **César Otaviano Penna Júnior[3]** [ID], **Maurício Novaes Souza[4]** [ID]

[1] Master's Degree in Agroecology. Federal Institute of Espírito Santo. ORCID: 0009-0001-0360-2205. Email: rodrigoleodias@gmail.com

[2] PhD in Plant Science. Federal Rural University of Rio de Janeiro. ORCID: 0000-0001-8315-4213. Email: fernando.ufrrj.agro@gmail.com

[3] PhD in Plant Production. Darcy Ribeiro State University of Northern Rio de Janeiro. ORCID: 0000-0002-2486-0932. Email: copenna@ifes.edu.br

[4] PhD in Water and Soil Engineering. Federal University of Viçosa. ORCID: 0000-0003-3100-6694. Email: mauricios.novaes@ifes.edu.br

RESUMO

Os sistemas agroflorestais têm se consolidado como uma abordagem inovadora para a produção agrícola sustentável, integrando de forma harmoniosa cultivos alimentares, espécies arbóreas e criação animal. Na região do Caparaó - ES, localizada no sul do Espírito Santo, estes sistemas adquirem especial relevância por conciliar a produção agrícola com a conservação dos remanescentes de Mata Atlântica, bioma prioritário para preservação. O presente estudo teve como objetivo principal avaliar a viabilidade econômica da produção agroecológica integrada em sistemas agroflorestais com cultivo de café em sete propriedades rurais participantes do programa Reflorestar, adotando uma abordagem metodológica que combinou técnicas qualitativas, incluindo entrevistas semiestruturadas com técnicos e produtores, com análises quantitativas baseadas em indicadores financeiros como Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR) e Relação Benefício/Custo (B/C). Os dados foram coletados durante o período de 2019 a 2024. Os principais resultados revelaram que, após um período inicial de investimento (2-4 anos), todos os SAFs atingiram patamares de rentabilidade robustos e sustentáveis no médio e longo prazo (horizonte de 30 anos). A viabilidade financeira foi consolidada a partir do 4° ao 6° ano, com indicadores finais notáveis: a TIR estabilizou-se em patamares entre 20,10% e 102,17%, o VPL variou de R$ 22.044,18 a R$ 175.140,49, e a relação B/C manteve-se entre 1,15 e 3,04, superando amplamente os retornos de sistemas convencionais. A diversificação da produção (café, banana, palmito, frutas nativas) mostrou-se decisiva para a resiliência econômica, amortecendo custos iniciais e garantindo múltiplas fontes de renda. Entrevistas com produtores destacaram a importância da escolha de variedades de café mais rústicas (como Arara) para reduzir custos, bem como desafios logísticos na comercialização de frutos perecíveis e na necessidade de manejo adequado de espécies consorciadas, como a banana. Os Sistemas Agroflorestais com café arábica são economicamente viáveis e representam uma alternativa superior aos modelos convencionais na região do Caparaó, conciliando alta rentabilidade financeira com benefícios ambientais e sociais. A plena potencialização deste modelo depende de um planejamento técnico rigoroso na seleção de espécies, acesso contínuo à assistência técnica especializada e do fortalecimento de canais de comercialização para os produtos diversificados, recomendando-se sua adoção e ampliação como estratégia de desenvolvimento rural sustentável.

Keywords: cafeicultura sustentável; sistemas integrados; análise financeira; conservação ambiental; desenvolvimento rural.

ABSTRACT

Agroforestry systems have established themselves as an innovative approach to sustainable agricultural production, harmoniously integrating food crops, tree species, and livestock. In the Caparaó region of Espírito Santo, located in southern Espírito Santo, these systems acquire special relevance by reconciling agricultural production with the conservation of remnants of the Atlantic Forest, a priority biome for preservation. This study aimed to evaluate the economic viability of integrated agroecological production in agroforestry systems with coffee cultivation on seven rural properties participating in the Reflorestar program, adopting a methodological approach that combined qualitative techniques, including semi-structured interviews with technicians and producers, with quantitative analyses based on financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Ratio (B/C). Data were collected during the period from 2019 to 2024. The main results revealed that, after an initial investment period (2-4 years), all Agroforestry Systems (AFS) reached robust and sustainable profitability levels in the medium and long term

2

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo
Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

(30-year horizon). Financial viability was consolidated from the 4th to the 6th year, with notable final indicators: the IRR stabilized at levels between 20.10% and 102.17%, the NPV ranged from R$ 22,044.18 to R$ 175,140.49, and the B/C ratio remained between 1.15 and 3.04, far exceeding the returns of conventional systems. Production diversification (coffee, bananas, palm heart, native fruits) proved decisive for economic resilience, offsetting initial costs and ensuring multiple income streams. Interviews with producers highlighted the importance of choosing more robust coffee varieties (such as Arara) to reduce costs, as well as logistical challenges in marketing perishable fruits and the need for adequate management of consorted species, such as bananas. Agroforestry Systems with arabica coffee are economically viable and represent a superior alternative to conventional models in the Caparaó region, combining high financial profitability with environmental and social benefits. The full potential of this model depends on rigorous technical planning in species selection, continuous access to specialized technical assistance, and the strengthening of commercialization channels for diversified products, recommending its adoption and expansion as a strategy for sustainable rural development.

Keywords: sustainable coffee farming; integrated systems; financial analysis; environmental conservation; rural development.

Introduction

Climate change poses a critical and growing threat to global production of *Coffea arabica* L., the world's most economically important coffee species (Craparo et al. 2015; Ovalle-Rivera et al. 2015). The increase in average and minimum temperatures, combined with changes in precipitation patterns and greater pressure from pests and diseases, has resulted in substantial declines in productivity and a progressive reduction in areas climatically suitable for cultivation (Tavares et al. 2018; Lorençone et al. 2023). This adverse situation jeopardizes the socioeconomic sustainability of millions of predominantly vulnerable smallholders and may exacerbate negative environmental impacts, such as deforestation resulting from agricultural expansion into new areas (Cassamo et al. 2023; Lorençone et al. 2023). In this context, the identification and implementation of effective and sustainable adaptation strategies are imperative for the resilience of the coffee sector (Merga and Alemayehu 2019; Wagner et al. 2021; Cassamo et al. 2023).

Agroforestry systems (AFS) emerge as an innovative and sustainable alternative for agricultural production, integrating trees, crops, and animals in the same space. This approach not only diversifies production but also optimizes the use of natural resources, such as water and soil nutrients, promoting greater production efficiency (Gomes et al. 2020; Lacerda et al. 2020). In addition to economic benefits, SAFs play a crucial role in environmental conservation, contributing to soil protection, nutrient cycling, and carbon sequestration, making them a viable strategy for adapting to climate change (Camargo et al. 2019).

Several studies conducted over the last decade have revealed the importance of traditional shade-grown coffee for the maintenance and protection of biodiversity. However, there is only biological exploration and no interdisciplinary exploration of the multiple values and benefits of these agroforestry systems (Toledo and Moguel 2012). This gap justifies the need for research that integrates economic, environmental, and social analyses, especially in regions such as Caparaó Capixaba, where family farming and the preservation of the Atlantic Forest are central themes.

In this context, this research seeks to assess the economic viability of integrated and sustainable agroecological production in the Caparaó region of Espírito Santo, in southern Espírito Santo. The study is based on the premise that agroecological systems (SAFs) can offer competitive financial returns, in addition to environmental and social advantages, such as income diversification and improved soil quality (SENAR 2017; Cerda et al. 2020; Zaro et al. 2020).

Thus, the overall objective of this study is to analyze the difference in economic returns from SAFs with coffee cultivation on seven family farms. As specific objectives, a detailed survey of data from the Reflorestar program in the region was conducted to assess the financial viability of the proposed arrangements.

Materials and Methods

Study area and data collection

The study followed a qualitative approach phase and a quantitative phase in the implementation of projects carried out by MV Gestão Integrada[1] (MVGI), offices in Alegre (ES) and Castelo (ES), since 2010, coordinated by the Alegre (ES) office, with funding and payments from the REFLORESTAR – BANDES program.

---

[1] Founded in 2018, MV Gestão Integrada is a consulting firm specializing in Payment for Environmental Services (PES) projects for the recovery of degraded areas. It is the main regional executor of the Reflorestar Program (one of the largest PES programs in Brazil) and representative of the Atlantic Forest Restoration Pact. Its activities include

3

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo
Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

In the qualitative phase, data was collected through semi-structured interviews with technicians and managers from MV Gestão Integrada, Alegre (ES) office. Observation was used as a collection tool, conducted from the implementation of the project until 2023.

The work was based on the analysis of information collected by MVGI, organized by the master's student together with producers who implemented SAFs starting in 2020. This data collection involved seven producers, in addition to the analysis of technical and economic data from their respective properties. The survey took place between August 15, 2024, and October 15, 2024. The agricultural production of the properties under their specific production arrangements was considered, with Arabica coffee being the central economic target crop. Table 1 presents all the information on the areas evaluated in this research. Table 2, in turn, presents the detailed characteristics of each property in relation to the municipality and the distribution of its areas in relation to the crops grown.

raising awareness among rural producers, planning, implementing, and monitoring projects, with more than 1,200 families served and 3,330 hectares under management (MV Gestão Integrada 2023) .

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo
Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

4

Table1 . Informative table of coffee production associated with the SAF of the properties evaluated in this study.

Property	System / Spatial arrangement	Species	Plot area	Spacing (m)	Area occupied by plant (m²)	No. of plants per plot	Number of plants per ha	Geographic coordinates
T1	4 rows of coffee + 1 row of bananas + 1 row of pupunha palm + 1 row of native species	Arabica coffee; Banana; Pupunha palm and native species	400m	Coffee: 2.5x1.5m; Banana: 2.5x4.0 m; Pupunha 2.5x4.0m; Native species 2.5x4.0m	Coffee: 3.75m²; Banana, pupunha palm, and native species: 10m²	Coffee: 53 plants; Banana, pupunha palm, and native species: 5 plants of each species	Coffee: 1,333 plants; Banana, peach palm, and native species: 125 plants of each species.	24K225910 / 7701656
T2	4 rows of coffee + 1 row of banana + 1 row of pupunha + 1 row of native species	Arabica coffee; Banana; Pupunha palm and native species	400m	Coffee: 3x1m; Banana: 3x4.0 m; Pupunha 3x4.0m; Native species 3x4.0m	Coffee: 3m²; Banana, pupunha palm, and native species: 12m²	Coffee: 80 plants; Banana, pupunha palm, and native species: 5 plants of each species	Coffee: 2,000 plants; Banana, peach palm, and native species: 125 plants of each species.	24K212047 / 7702845
T3	4 rows of coffee + 2 rows of banana + 1 row of native species	Arabica coffee; Banana and native species	400m	Coffee: 3x1m; Banana: 3x4.0 m; Native species 3x4.0m	Coffee: 3m²; Banana and native species: 12m²	Coffee: 80 plants; Banana 10 plants and native plants 5 plants	Coffee: 2000 plants; Banana 250 plants and native species 125 plants.	24K225029 / 7696590
T4	4 rows of coffee + 2 rows of pupunha palm + 1 row of native species	Arabica coffee; Pupunha palm hearts and native species	400m	Coffee: 3x1m; Pupunha: 3x4.0 m; Native species 3x4.0m	Coffee: 3m²; Pupunha and native species: 12m²	Coffee: 80 plants; Pupunha 10 plants and native species 5 plants	Coffee: 2,000 plants; Pupunha 250 plants and native species 125 plants.	24K212002/ 7702801
T5	3 rows of coffee + 1 row of bananas + 1 row of pupunha + 1 row of native species	Arabica coffee; Banana; Pupunha palm and native species	400m•	Coffee: 3x1m; Banana: 3x4.0m; Pupunha palm: 3x4.0m; Native trees: 3x4.0m	Coffee: 3m²; Banana, pupunha palm, and native species: 12m²	Coffee: 60 plants; Banana, peach palm, and native species: 5 plants of each species	Coffee: 1,500 plants; Banana, peach palm, and native species: 125 plants of each species.	24K212732 / 7706961
T6	3 rows of coffee + 1 row of banana + 1 row of pupunha + 1 row of native species	Arabica coffee; Banana; Pupunha palm and native species	400m	Coffee: 3x1m; Banana: 3x4.0 m; Pupunha 3x4.0m; Native species 3x4.0m	Coffee: 3m²; Banana, pupunha palm, and native species: 12m²	Coffee: 60 plants; Banana, pupunha palm, and native species: 5 plants of each species	Coffee: 1,500 plants; Banana, peach palm, and native species: 125 plants of each species.	24K213071 / 7706455
T7	Coffee planted in total area; pupunha palm planted between coffee rows and every 2 rows of coffee, native species planted randomly	Arabica coffee, peach palm, and native species	400m	Coffee: 3x1.5m; Pupunha: 1.5x3m; Native species randomly	Coffee: 4.5m; Pupunha: 4.5m	Coffee: 16 plants; Pupunha 3; Native species: 3	Coffee: 2,222 plants; Pupunha: 417 plants; Native species: 150 plants	24K210138 / 7710721

Source: Prepared by the authors (2025)

5

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Table 2. General characterization of rural properties studied in the state of Espírito Santo, Brazil

Property	Total Area (ha)	Cultivated Species (Areas in ha)	Municipality
T1 (Figure 1)	10.5047	Coffee Arara (*Coffea arabica*) (0.5 ha); Banana (0.125 ha); Uvaia (*Eugenia pyriformis*); Avocado (*Persea americana*); Mango (*Mangifera indica*)	Guaçuí - ES
T2 (Figure 2)	19.0516	Catucaí Amarelo 785/15 coffee (*Coffea arabica*) (0.6 ha); Banana (0.125 ha); Uvaia (*Eugenia pyriformis*) (0.125 ha); Avocado (*Persea americana*); Mango (*Mangifera indica*)	Guaçuí - ES
T3 (Figure 3)	2.2268	Coffee 785/15 (*Coffea arabica*) (0.6 ha); Banana (0.3 ha); Uvaia (*Eugenia pyriformis*) (0.125 ha); Avocado (*Persea americana*) (0.125 ha); Mango (*Mangifera indica*) (0.125 ha)	Guaçuí - ES
T4 (Figure 4)	16.3911	Catucaí 785/15 coffee (*Coffea arabica*) (0.6 ha); Banana (0.125 ha); Uvaia (*Eugenia pyriformis*); Jussara palm (*Euterpe edulis*)	Alegre - ES
T5 (Figure 5)	25.175	Arara coffee (*Coffea arabica*) (0.45 ha); Banana (0.125 ha); Jussara palm heart (*Euterpe edulis*)	Guaçuí - ES
T6 (Figure 6)	10.457	Catucaí 785/15 coffee (*Coffea arabica*) (0.45 ha); Banana (0.6 ha); Uvaia (*Eugenia pyriformis*); Jussara palm heart (*Euterpe edulis*)	Guaçuí - ES
T7 (Figure 7)	16.3911	Yellow Catucaí Coffee 785/15 (*Coffea arabica*) (0.6 ha); Banana (0.3 ha); Uvaia (*Eugenia pyriformis*); Avocado (*Persea americana*); Mango (*Mangifera indica*)	Alegre - ES

Source: Prepared by the authors (2025).

6

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza
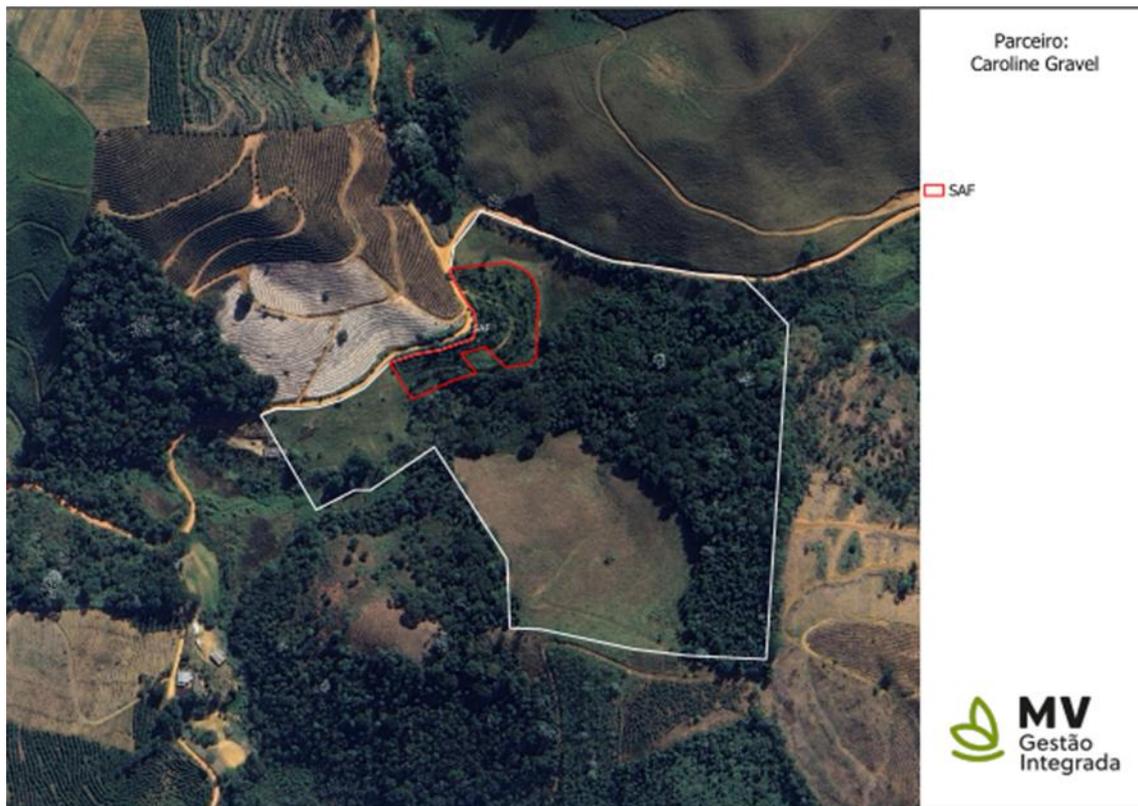
Figure 1. Family-owned property called Sítio Gravel 2 (T1). Located 12 km from the center of the city of Guaçuí, ES, Brazil. Source: prepared by the authors (2025).
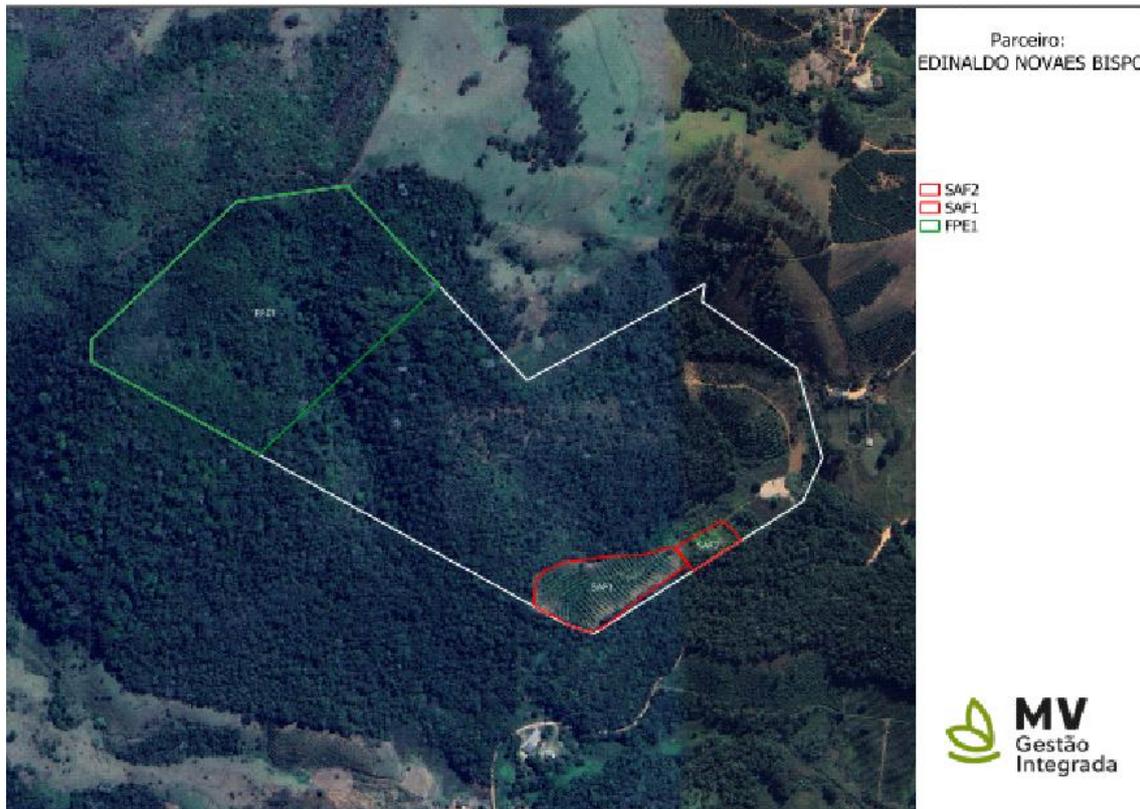
7

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo
Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Figure 2. Family-based property (T2) located 17 km from the center of the city of Guaçuí, ES, Brazil. Source: prepared by the authors (2025).
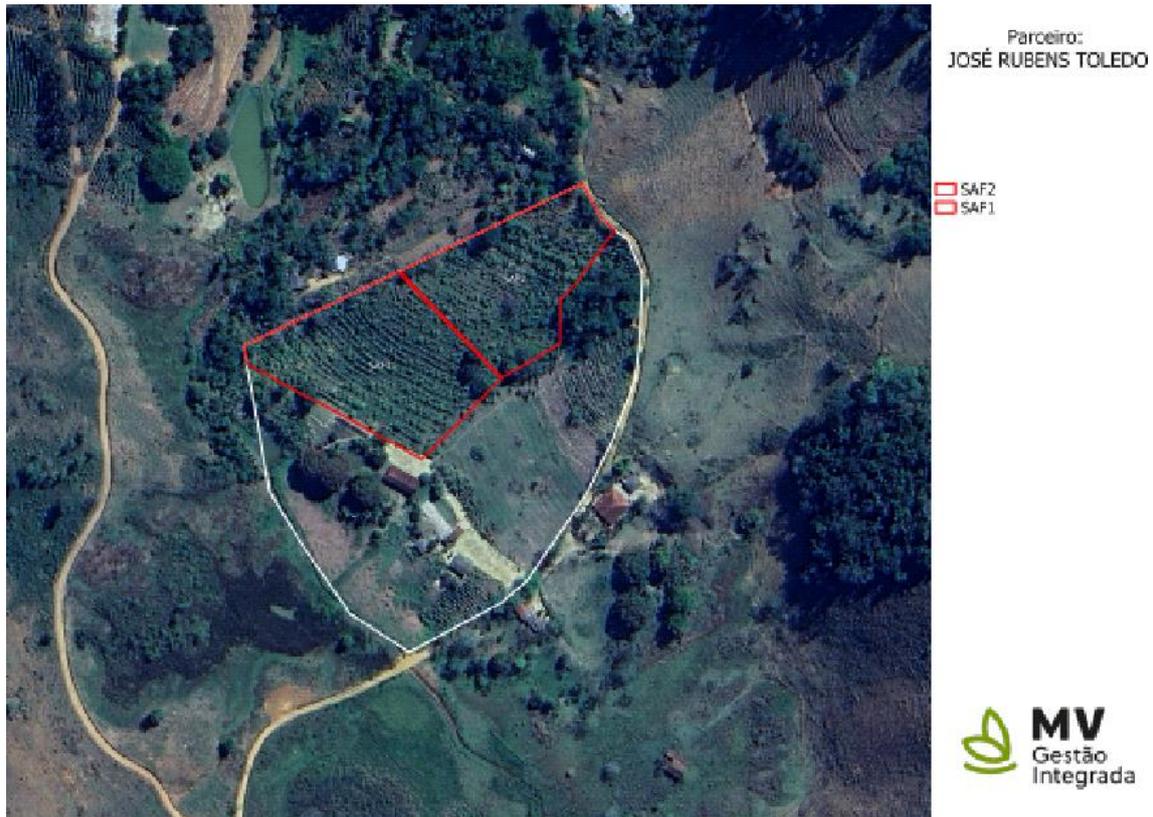
8

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo
Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Figure 3. Family-based property (T3) located 10 km from the center of the city of Guaçuí, ES, Brazil. Source: prepared by the authors (2025).

9

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Figure 4. Family-based property (T4) located 20 km from the center of the city of Alegre, ES, Brazil. Source: prepared by the authors (2025).

10

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Figure 5. Family-based property Sítio Gravel (T5), located 19 km from the center of the city of Guaçuí, ES, Brazil. Source: prepared by the authors (2025).

Figure 6. Family-based property Sítio São Romão (T6), located 12 km from the center of the city of Guaçuí, ES, Brazil. Source: prepared by the authors (2025).

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

12

Figure 7. Family-based property (T7) located 20 km from the center of the city of Alegre, ES, Brazil. Source: prepared by the authors (2025).

In the quantitative phase, data was calculated in a cash flow from the producer for the application of capital investment techniques, as described below. The data was entered into Excel spreadsheets to calculate revenues, variable costs and expenses, fixed costs and expenses, taxes, and depreciation, thus obtaining the producer's free cash flow.

Methods for analyzing capital investment

To analyze investment in the areas studied, a ten-year period was considered, according to Richetti, Motta, and Padovan (2011), who define this interval to examine the economic feasibility of sustainable agricultural production and forestry. The economic feasibility analysis was carried out over the last five years, since some

farmers accessed the REFLORESTAR project between 2019 and 2024. The fixed investment value for the implementation of PES (Payment for Environmental Services) areas was allocated in full in years 1 and 2. Regarding the feasibility assessment, the producer's free cash flow was initially calculated. The investment techniques used in this study are presented in Table 3.

Table 3. Economic indicators used in the research.

Indicator (Acronym)	Definition	Formula
Internal Rate of Return (IRR)	Rate that sets the Net Present Value to zero.	$TIR = \sum_{t=0}^{n} \frac{FC_t}{(1+r)^t}$
Modified Internal Rate of Return (MIRR)	Rate considering capitalization of inflows and discounting of outflows.	$TIRM = \left(\frac{VF\ entradas}{VP\ saídas}\right)^{\frac{1}{n}} - 1$
Net Present Value (NPV)	Difference between present values of inflows and outflows.	$VPL = \sum_{t=0}^{n} \frac{FC_t}{(1+i)^t}$
Benefit/Cost Ratio (B/C)	Ratio between updated benefits and costs.	$BC = \left(\frac{VP\ benefícios}{VP\ custos}\right)$
Equivalent Uniform Annual Value (EUAV)	Annualization of NPV.	$VAUE = VPL \times \sum_{t=0}^{n} \frac{i(1+i)^n}{(1+i)^n - 1}$
Return on Investment (ROI)	Return on investment.	$ROI = \left(\frac{Receitas - Despesas}{Despesas}\right)$
Revenues (R)	Sum of monetary inflows.	$Receitas = \sum_{t=1}^{n} R_t$
Expenses (E)	Sum of monetary outflows.	$Despesas = \sum_{t=1}^{n} D_t$

CF: Cash flow; i: Discount rate; n: Analysis horizon; r: Internal rate of return that zeroes the NPV; R: Revenues; D: Expenses; $FV_{inflows}$: Future value of inflows; $PV_{outflows}$: Present value of outflows. Source: prepared by the authors (2025).

According to Ferraz et al. (2024), for the economic feasibility analysis of SAFs, the venture is considered feasible if the IRR exceeds the Minimum Attractiveness Rate (MAR). To estimate income generation from agroforestry products, production data obtained from the literature and market research at the time of the analysis were used, adapted to the planting density of each SAF evaluated in the study.

Results and Discussion

Reports from producers

The producer of the T1 property reported that the Arara coffee variety stands out for its high resistance to disease and superior productivity, reducing the need for intensive cultural practices and, consequently, production costs, although it still requires the application of inputs to the soil for a good yield. Bananas are well accepted in the local market, with a large part of the production destined for the PNAE and PAA programs. Uvaia faces marketing difficulties due to its extreme perishability, requiring freezing and specific storage. Mangoes and avocados are sold in the local market based on CEASA-ES prices.

According to the report from the producer on property 2, the Catucaí coffee variety requires more intensive cultivation, increasing production costs and negatively impacting economic returns when compared to more resistant varieties. Bananas remain well accepted in the market and are sold in small markets and points of sale in the city. Uvaia fruits are intended exclusively for subsistence and family consumption. Mangoes and avocados are absorbed by the local market at prices guided by CEASA-ES.

The producer on property T3 indicated that the 785/15 coffee variety requires intensive management and the application of specific techniques, which increases production costs and results in lower economic returns. The BRS Anã (Terra) variety of banana is well accepted in the local market, but the producer warned of an unforeseen problem in the project: the need to replant every four years due to the weakening of the clumps, which adds costs and labor not initially budgeted.

Producers on the T4 property reported that the Catucaí 785/15 variety requires specific management techniques and its yield can be affected by intercropping in the Agroforestry System (SAF). However, they value the quality of life provided by the system, prioritizing it over maximizing coffee production. Bananas are well accepted in the local market, with direct sales and commercial agreements. The jussara palm heart crop has satisfactory production, with a commercial agreement established with a local business and adequate management.

The producer of property T5, similar to T1, highlighted the benefits of the Arara variety, such as high disease resistance and lower input requirements, reducing costs and providing better economic returns. Bananas are mainly marketed through the PNAE and PAA programs. Jussara palm hearts show satisfactory performance, with a sales agreement with a local retailer and adequate management to optimize results.

Producers on property T5, with a history of conventional coffee, negatively evaluate the agroforestry arrangement, stating that the Catucaí 785/15 variety does not produce well in consortium. They reported problems with banana cultivation, specifically the 'da terra' variety, citing excessive height growth, weakening of the clumps, and the need for frequent replanting, factors that make it unsuitable for long-term arrangements. The commercialization of jussara palm hearts, on the other hand, is done through local agreements, and its production is considered satisfactory.

The producer on property T7 reported that the Catucaí Amarelo 785/15 variety requires intensive cultivation and the application of inputs, increasing production costs compared to more rustic varieties. Bananas sell well on the market, with a marketing channel focused on the PNAE and PAA programs. Uvaia faces logistical barriers to marketing due to its rapid ripening and need for refrigerated storage. Mangoes and avocados are sold on the local market based on CEASA-ES prices.

Financial analysis of investments in different properties

The financial feasibility assessment of the agroforestry venture, projected over a 30-year horizon, reveals a classic medium- to long-term investment profile, marked by an initial phase of significant capital absorption followed by a consolidation of positive and stable returns. The first two years are characterized by an intense investment cycle, with the Modified Internal Rate of Return (MIRR) reaching -100% and -72.22%, respectively (Figure 8-B), reflecting the high financial risk inherent in the system implementation phase. This period is corroborated by a deeply negative Net Present Value (NPV) (-R$38,479.54 in Year 1 and -R$35,979.43 in Year 2) (Figure 8-C) and a Return on Investment (ROI) of -75.92% and -54.67% (Figure 8-F), showing that implementation costs substantially exceed incipient revenues. The Benefit/Cost (B/C) ratio of 0.24 and 0.45 (Figure 8-D) confirms that the benefits generated cover less than half of the operating and investment costs, a scenario expected for this stage.

The financial turnaround occurs decisively between the fourth and fifth years. In Year 4, the IRR reaches a positive value of 7.17% (Figure 8-A), and the B/C ratio approaches unity (0.98) (Figure 8-D), signaling the point of financial equilibrium. In Year 5, economic viability is consolidated: the IRR jumps to 18.58% (Figure 8-A), the NPV becomes positive (R$14,153.04) (Figure 8-C), and the B/C ratio exceeds the critical threshold (1.14) (Figure 8-D), demonstrating that the project has started to generate net value. The positive ROI of 13.69% (Figure 8-F) confirms that the invested capital has begun to be recovered with gains.

From the sixth year onwards, the project reaches operational maturity and financial stability, with all indicators remaining constant and positive until the end of the analysis horizon. The IRR stabilizes at 25.94% (Figure 8-A), indicating a robust and attractive rate of return. The NPV consolidates at R$31,893.71 (Figure 8-C), and the Uniform Annual Equivalent Value (VAUE) shows a slight decline (from R$7,109.74 to R$3,104.42) (Figure 8-E) due to the extension of the analysis period, but always remaining positive, which attests to the profitability of the investment over time. The B/C ratio remains at 1.28 (Figure 8-D), indicating that for each real invested, R$1.28 in benefits is returned. The ROI stabilizes at 27.99% (Figure 8-F), denoting consistent efficiency in generating profit on invested capital.

15

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

The analysis of revenues and expenses corroborates this successful trajectory. Revenues show significant growth until the sixth year (from R$12,201.83 to R$145,828.47) (Figure 8-G), stabilizing at this high level. Notably, from Year 5 onwards, revenues consistently exceed expenses, which stabilize at R$113,934.75 (Figure 8-H), resulting in a positive and growing net operating cash flow. This dynamic demonstrates efficient operational management, with adequate cost control and production scalability. Despite the substantial initial outlay and the development period characteristic of agroforestry systems, the project demonstrates the ability to generate solid, sustainable, and attractive financial returns in the medium and long term, validating the investment strategy and the effectiveness of the management model adopted.

The assessment of the financial performance of the agroforestry system on Property T2 reveals a trajectory of remarkable recovery and economic robustness. Initially, the characteristic pattern of implementation investments is observed. The first year shows a Modified Internal Rate of Return (MIRR) of -100% (Figure 9-B) and a Return on Investment (ROI) of -78.34% (Figure 9-F), reflecting the high capital expenditure. This scenario is confirmed by a Net Present Value (NPV) of -R$46,456.41 (Figure 9-C) and a Benefit/Cost (B/C) ratio of 0.22 (Figure 9-D), indicating that the costs far outweigh the initial benefits.

However, the transition to profitability occurs rapidly and vigorously. In the third year, the Internal Rate of Return (IRR) is still negative (-2.09%) (Figure 9-A), but the MIRR shows a significant recovery to -1.02% (Figure 9-B), signaling the imminence of the break-even point. The consolidation of economic viability materializes decisively in the fourth year, with the IRR reaching 17.46% (Figure 9-A) and the NPV becoming positive (R$12,147.29) (Figure 9-C). The B/C ratio, exceeding unity (1.10) (Figure 9-D), and the positive ROI (10.28%) (Figure 9-F) corroborate that the project began to generate net value and an adequate return on investment.

16

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza
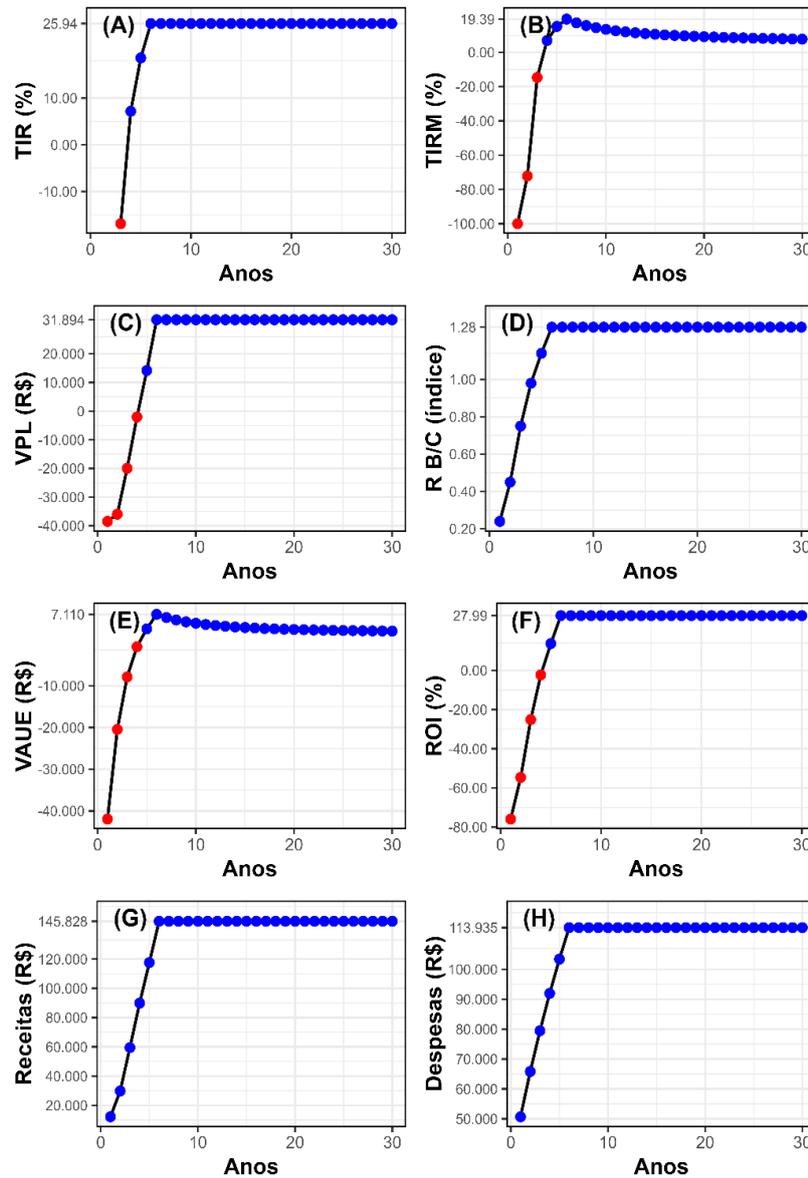
Figure 8. Economic and financial feasibility analysis for Property T1, municipality of Guaçuí, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

Operational maturity is achieved in the sixth year, with indicators stabilizing at exceptional levels. The IRR stabilizes at 37.04% (Figure 9-A), a remarkably high value, demonstrating an extremely attractive rate of return. The NPV reaches R$70,531.42 (Figure 9-C), and the Uniform Annual Equivalent Value (VAUE) begins its stable trajectory at R$15,722.85 (Figure 9-E). The B/C ratio remains at 1.47 (Figure 9-D), indicating high efficiency in converting costs into benefits, while the ROI consolidates at 46.82% (Figure 9-F), evidencing exceptional and sustained profitability.

Cash flow analysis reveals the basis for this superior performance. Revenues show exponential growth through the sixth year, jumping from R$12,844.04 to R$221,187.34 (Figure 9-G). From that point on, they stabilize at a level significantly higher than expenses, which stand at R$150,655.91 (Figure 9-H). This dynamic results in a substantial and consistent net operating margin, underscoring the venture's productive efficiency and excellent cost management. The combination of an accelerated recovery, robust profitability indicators, and the generation of substantial net cash flow positions the T2 property venture as a model of high economic performance within the study universe.
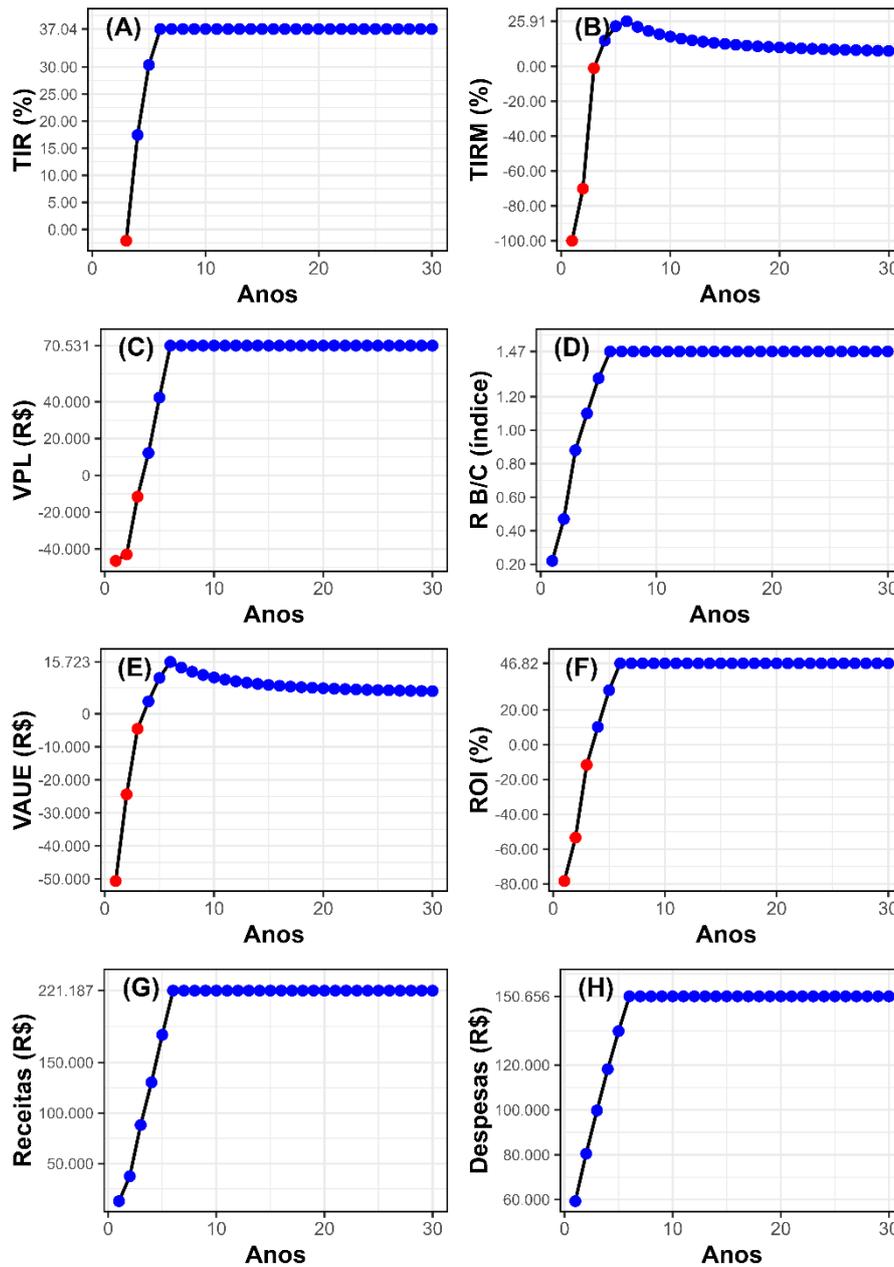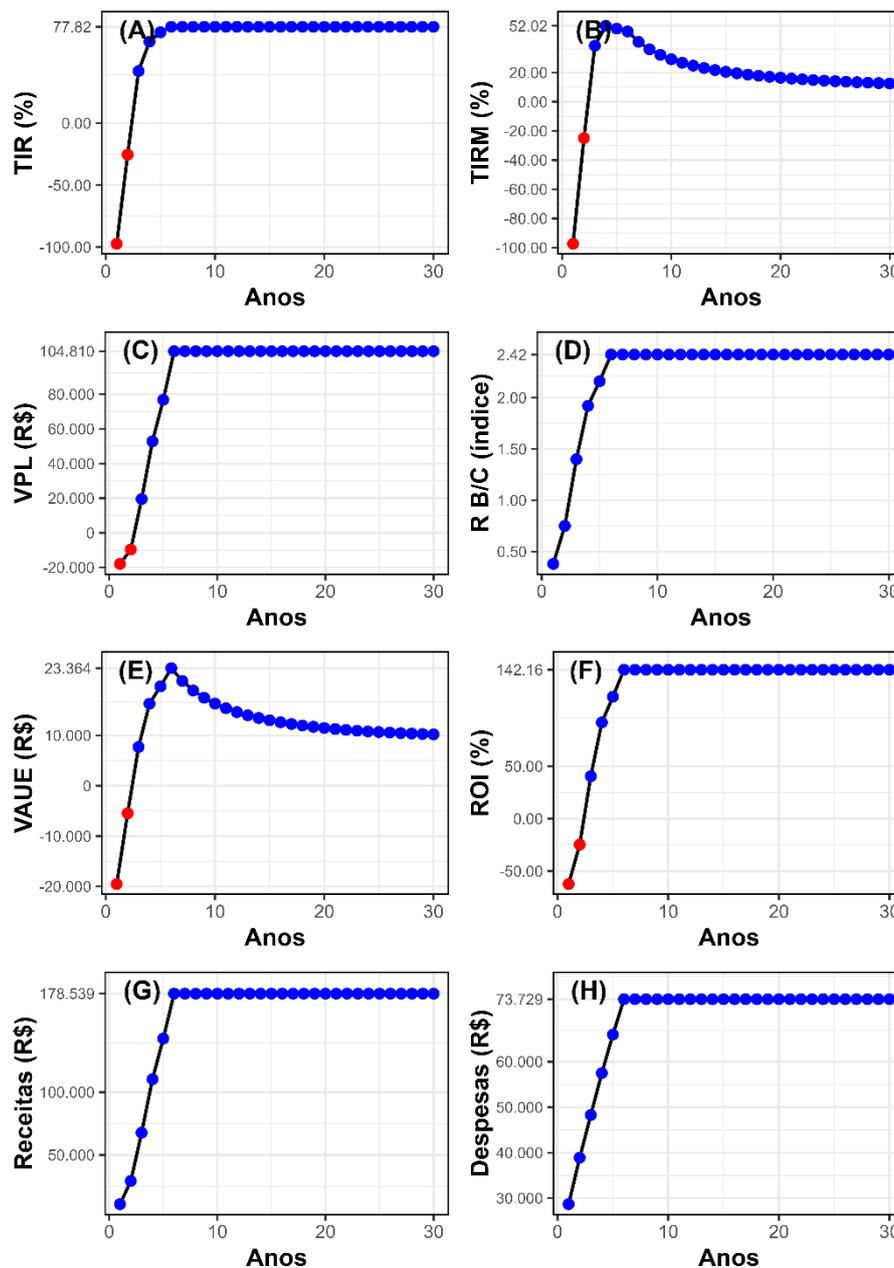
Figure 9. Economic and financial feasibility analysis for Property T2, municipality of Guaçuí, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

The economic and financial analysis of agricultural property T3 over 30 years initially shows high capital investments, reflected in negative IRR and MIRR of −97.30% in the first year (Figure 10-A), which indicate the intense application of resources in the implementation phase and high initial financial risk. The NPV ( ) (Figure 10-B) and VAUE (Figure 10-C) follow a similar pattern, negative in the first years (−17,907.55 and −19,519.23, respectively), highlighting the impact of the initial outlay on the project's liquidity.

18

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Figure 10. Economic and financial feasibility analysis for Property T3, municipality of Guaçuí, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

The B/C ratio (Figure 10-D) starts at 0.38, confirming that costs exceed benefits in the initial phase, while the ROI (Figure 10-E) is −62.40%, characterizing a negative return on invested capital. From the third year onwards, there is a rapid financial recovery, with positive IRR and MIRR (42.12% and 38.33%, respectively), positive NPV (19,508.69) and accumulated EVAL of 7,707.00, while the B/C ratio exceeds unity (1.40) and the ROI becomes positive (40.42%), indicating that the project begins to generate economic value and an adequate return on investment. This growth stabilizes from the sixth year onward, wh , IRR and MIRR reach 77.82% and 48.11%, NPV and VAUE reach 104,810.20 and 23,364.27, the B/C ratio reaches 2.42, and ROI reaches 142.16%, demonstrating high economic efficiency and financial sustainability. Revenues (Figure 10-F) increase progressively, from 10,788.99 in the first year to 178,538.76 from the sixth year onwards, while expenses (Figure 10-G) remain significantly lower, at 73,728.57, indicating efficient operational management and cost control.

The integration of these indicators shows that, despite the high initial investment, the T3 property project has consistent economic and financial viability, high returns, and continuous value generation, highlighting the

importance of financial planning, strategic resource management, and continuous performance monitoring to maximize the efficiency and sustainability of agricultural enterprises.

The evaluation of the financial performance of the agroforestry system implemented on Property T4 reveals an exemplary case of economic viability, characterized by extremely rapid recovery. Unlike the other cases presented, this property has a unique return curve, with the Internal Rate of Return (IRR) already calculable in the first year, registering -60.97% (Figure 11-A), a value equal to the Modified Internal Rate of Return (MIRR) (Figure 11-B). This data, associated with a Return on Investment (ROI) of -38.91% (Figure 11-F) – the least negative among all properties in the initial year – and a Benefit/Cost (B/C) ratio of 0.61 (Figure 11-D), suggests a distinct investment profile, with a potentially shorter or more intensive initial investment cycle.

The financial turnaround occurs early and vigorously in the second year. The IRR jumps to 16.26% (Figure 11-A) and the Net Present Value (NPV) becomes decisively positive (R$4,145.92) (Figure 11-C), while the B/C ratio reaches 1.10 (Figure 11-D), marking the break-even point. This is the fastest payback observed in the study, indicating unparalleled efficiency in cash flow generation.

From the third year onwards, the project reaches and maintains extraordinary levels of profitability. The IRR reaches 72.38% (Figure 11-A), evolving to a peak of 101.65% from the sixth year onwards (Figure 11-A), an absolutely exceptional return indicator. The NPV shows exponential growth, stabilizing at R$175,140.49 (Figure 11-C), the highest absolute value reported. The B/C ratio reaches 3.04 (Figure 11-D), meaning that for every real invested, R$3.04 in benefits are returned, demonstrating superlative economic efficiency. The ROI, in turn, stabilizes at 204.41% (Figure 11-F), corroborating sustained and vastly superior profitability.

The cash flow analysis reveals the basis for this unparalleled performance. Revenues show meteoric growth, climbing from R$17,941.75 to R$260,820.88 (Figure 11-G). Notably, from the second year onwards, revenues not only exceed expenses but also represent a very wide operating margin, with expenses stabilizing at R$85,680.39 (Figure 11-H) against revenues three times higher. This dynamic highlights an operational model of extremely high efficiency, low cost, and robust production scalability. The combination of an extremely accelerated return on capital, profitability indicators that reach levels rarely seen in agricultural enterprises, and the generation of a robust and growing cash flow positions the T4 property as a model of economic excellence and productive efficiency.

The assessment of the financial performance of the agroforestry system at Property 5 shows a solid and consistent investment profile, characterized by an initial maturation period followed by stabilization at profitable levels, reflecting a typical trajectory of successful agricultural enterprises (Figure 12). The initial implementation phase shows the expected negative indicators, but less severe than on other properties. The first year is marked by a Modified Internal Rate of Return (MIRR) of -100% (Figure 12-B) and a Return on Investment (ROI) of -74.04% (Figure 12-F), accompanied by a Net Present Value (NPV) of -R$43,518.70 (Figure 12-C) and a Benefit/Cost (B/C) ratio of 0.26 (Figure 12-D), indicative of the conventional cycle of initial investments.

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza
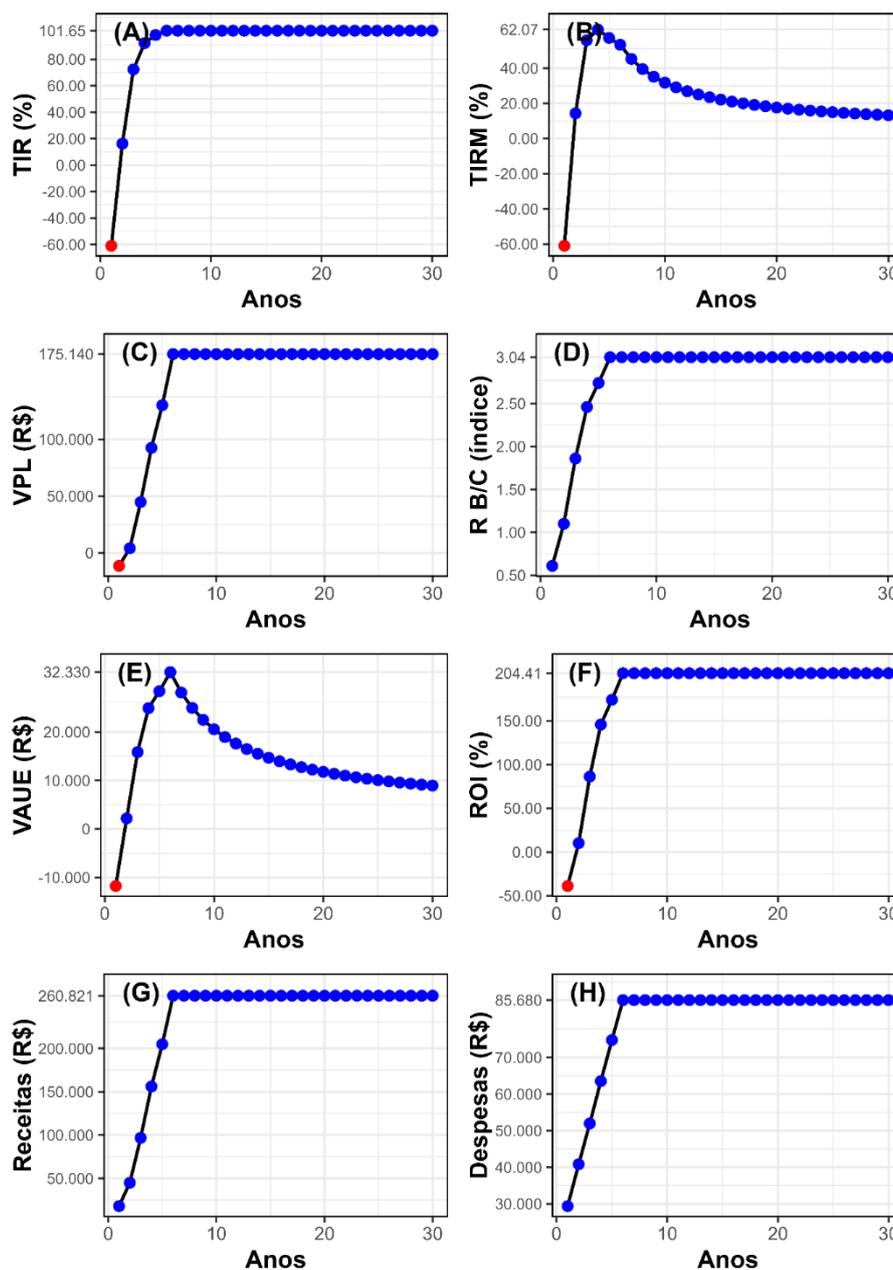
20

Figure 11. Economic and financial feasibility analysis for Property T4, municipality of Alegre, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

The transition to profitability follows a gradual trajectory. In the second year, the Internal Rate of Return (IRR) reaches -64.61% (Figure 12-A), evolving to -6.87% in the third year (Figure 12-A), rapidly approaching the break-even point. The financial turnaround is decisively consolidated in the fourth year, when the IRR reaches 9.98% (Figure 12-A), the NPV becomes positive (R$1,192.51) (Figure 12-C), and the B/C ratio exceeds unity (1.01) (Figure 12-D), marking the moment when the project begins to generate net economic value.

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza
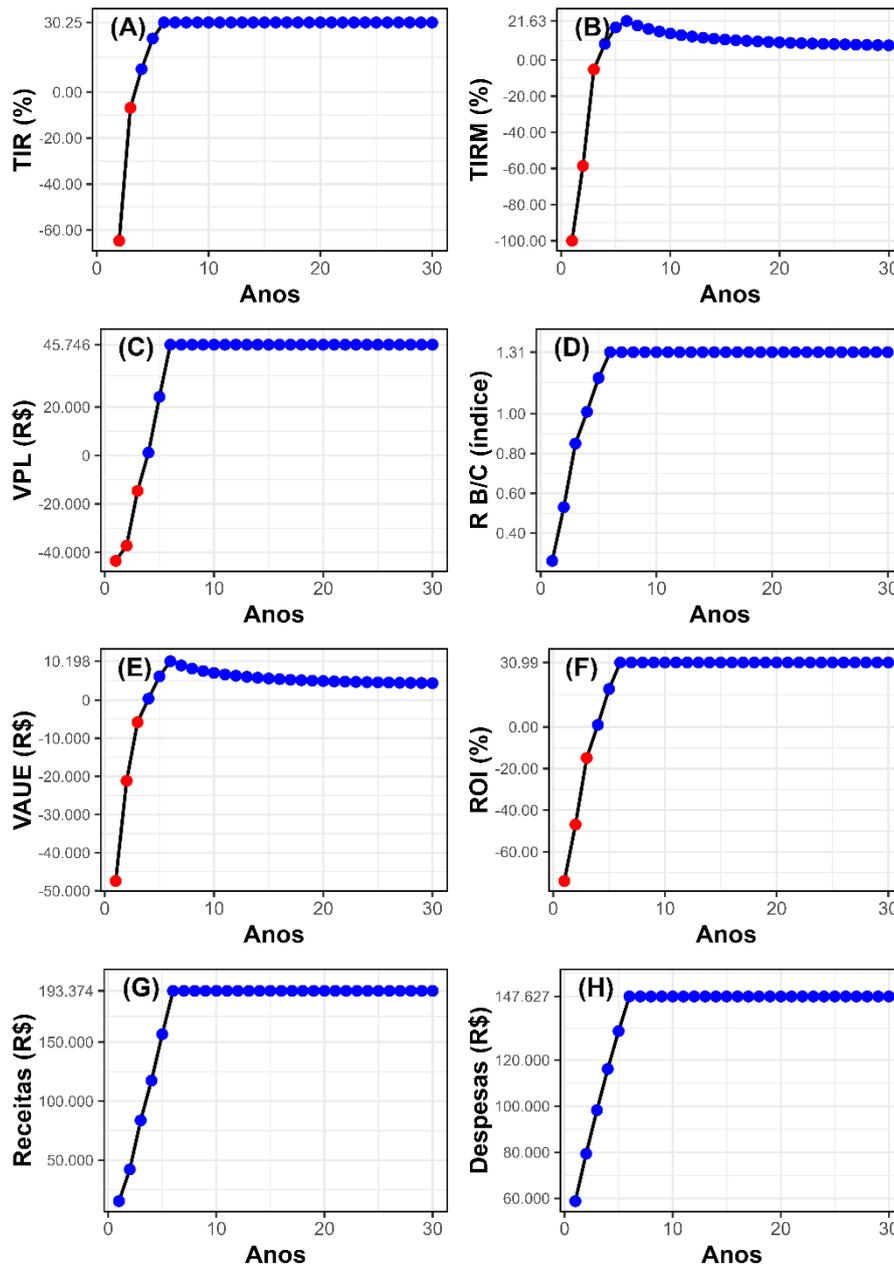
21

Figure 12. Economic and financial feasibility analysis for Property T5, municipality of Guaçuí, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

Operational maturity is achieved in the sixth year, with indicators stabilizing at consistently positive levels. The IRR stabilizes at 30.25% (Figure 12-A), demonstrating a robust and attractive rate of return. The NPV consolidates at R$45,746.33 (Figure 12-C), while the Uniform Annual Equivalent Value (VAUE) begins its stable trajectory at R$10,197.76 (Figure 12-E). The B/C ratio remains at 1.31 (Figure 12-D), indicating an efficient conversion of costs into benefits, and the ROI stabilizes at 30.99% (Figure 12-F), reflecting sustained and adequate profitability.

Cash flow analysis reveals the basis for this consistent performance. Revenues show steady growth through the sixth year, rising from R$15,258.72 to R$193,373.76 (Figure 12-G). From this point on, they stabilize at a level significantly higher than expenses, which stand at R$147,627.43 (Figure 12-H) ( ), resulting in a positive and stable net operating margin, demonstrating efficient cost control and sustainable income generation capacity.

The results show that the production system at Property 5 has proven economic and financial viability, with a gradual and consistent return profile. The combination of solid profitability indicators, stable cash flow, and positive operating margins positions this venture as a moderate success story, representing a reliable model for medium-term agroforestry investment.

The assessment of the financial performance of the agroforestry system on Property T6 reveals an investment profile characterized by a longer maturation period, followed by stabilization at moderately profitable levels, reflecting a conservative but consistent long-term return trajectory. The initial implementation phase shows indicators compatible with long-term investments. The first two years show a Modified Internal Rate of Return (MIRR) of -100% (Figure 13-B), with a Net Present Value (NPV) of -R$43,235.88 and -R$43,265.27, respectively (Figure 13-C), and a Return on Investment (ROI) of -73.91% and -54.79% (Figure 13-F). The Benefit/Cost (B/C) ratio of 0.26 and 0.45 (Figure 13-D) confirms the expected initial imbalance between investments and returns.

The transition to profitability occurs gradually between the fourth and fifth years. In the fourth year, the Internal Rate of Return (IRR) reaches 2.59% (Figure 13-A), approaching the break-even point, while the B/C ratio reaches 0.93 (Figure 13-D). The financial turnaround is consolidated in the fifth year, when the IRR reaches 12.23% (Figure 13-A), the NPV becomes positive (R$5,023.68) (Figure 13-C), and the B/C ratio exceeds unity (1.04) (Figure 13-D), marking the beginning of net economic value generation.

Operational maturity is achieved from the sixth year onwards, with indicators stabilizing at moderate but consistent levels. The IRR stabilizes at 20.10% (Figure 13-A), demonstrating an acceptable rate of return. The NPV consolidates at R$22,044.18 (Figure 13-C), while the Equivalent Uniform Annual Value (VAUE) begins its stable trajectory at R$4,914.08 (Figure 13-E). The B/C ratio remains at 1.15 (Figure 13-D), indicating a positive margin between benefits and costs, and the ROI stabilizes at 14.99% (Figure 13-F), reflecting moderate but sustainable profitability.

The cash flow analysis reveals steady revenue growth through the sixth year, evolving from R$15,258.72 to R$169,150.75 (Figure 13-G). From this point on, revenues stabilize at a level consistently higher than expenses, which stand at R$147,106.56 (Figure 13-H), resulting in a positive net operating margin, albeit more modest than on other properties, demonstrating adequate cost control and the ability to generate stable income.

The results show that the production system at Property 6 has proven economic and financial viability, with a more conservative return profile. The combination of moderate profitability indicators, stable cash flow, and positive operating margins positions this venture as a case of sustainable economic viability, representing a model of agroforestry investment with a gradual but secure return.

The assessment of the financial performance of the agroforestry system implemented on Property T7 reveals an exemplary case of economic success, characterized by extremely rapid recovery and exceptional profitability indicators, positioning it as one of the most profitable ventures in the study. Unlike most properties, this production unit has a unique return curve from the first year, with an Internal Rate of Return (IRR) of -60.42% (Figure 14-A) and a Modified Internal Rate of Return (MIRR) at the same level (Figure 14-B). This initial outlook, combined with a Return on Investment (ROI) of -40.77% (Figure 14-F) – significantly less negative th n other properties – and a Benefit/Cost (B/C) ratio of 0.59 (Figure 14-D), suggests a distinct investment profile with lower initial capital requirements.
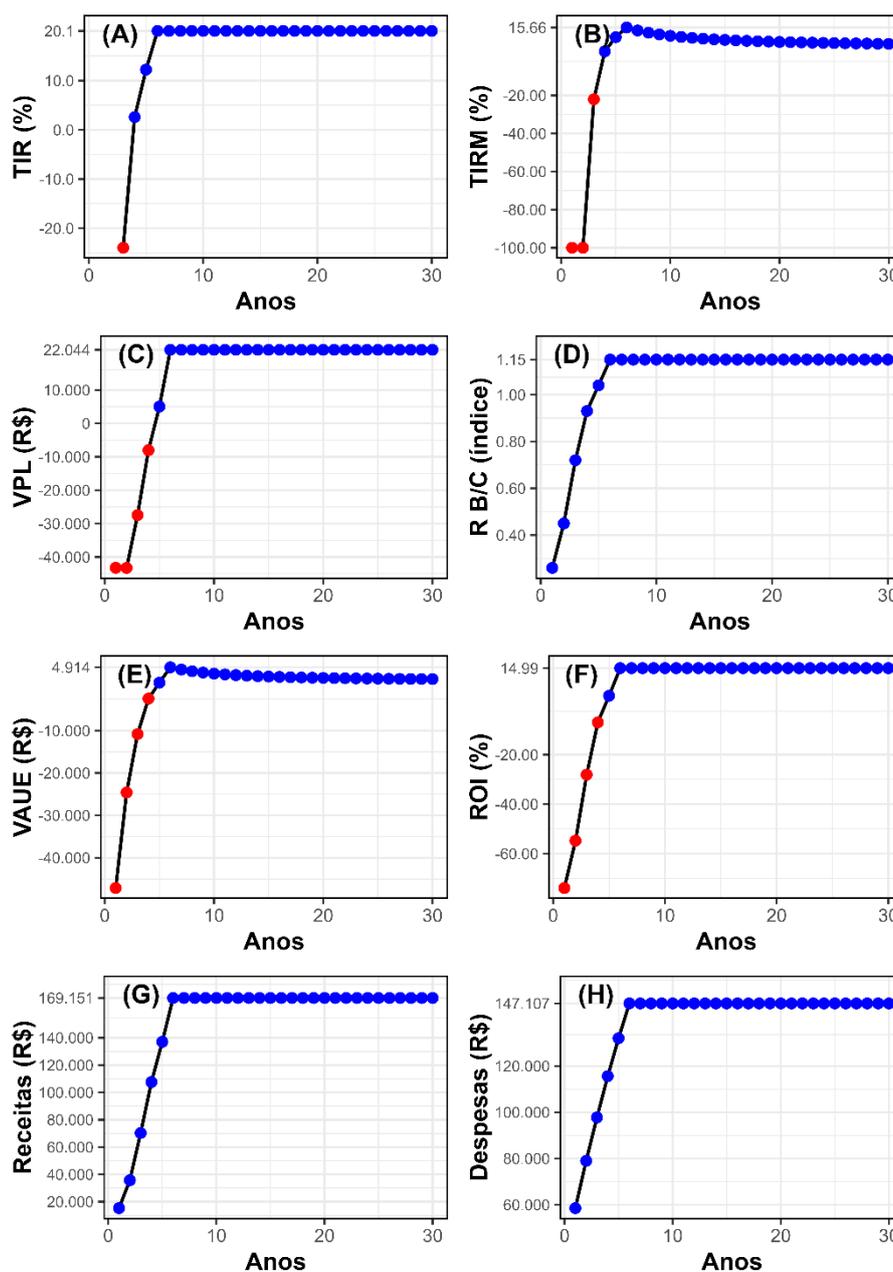
Figure 13. Economic and financial feasibility analysis for Property T6, municipality of Guaçuí, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

The financial turnaround occurs early and vigorously in the second year. The IRR jumps to 16.98% (Figure 14-A) and the Net Present Value (NPV) becomes positively significant (R$2,295.05) (Figure 14-C), while the B/C ratio reaches 1.06 (Figure 14-D), surpassing the break-even point early on. This accelerated recovery represents the fastest payback observed among comparable properties.

From the third year onwards, the project reaches extraordinary levels of profitability. The IRR reaches 73.02% (Figure 14-A), evolving to a peak of 102.17% from the sixth year onwards (Figure 14-A), representing an exceptional return indicator ( ). The NPV shows exponential growth, stabilizing at R$135,087.99 (Figure 14-C). The B/C ratio reaches 2.84 (Figure 14-D), indicating that for every real invested, R$2.84 in benefits are returned, demonstrating superlative economic efficiency. The ROI, in turn, stabilizes at 183.55% (Figure 14-F), corroborating sustained and vastly superior profitability.

24

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo
Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza
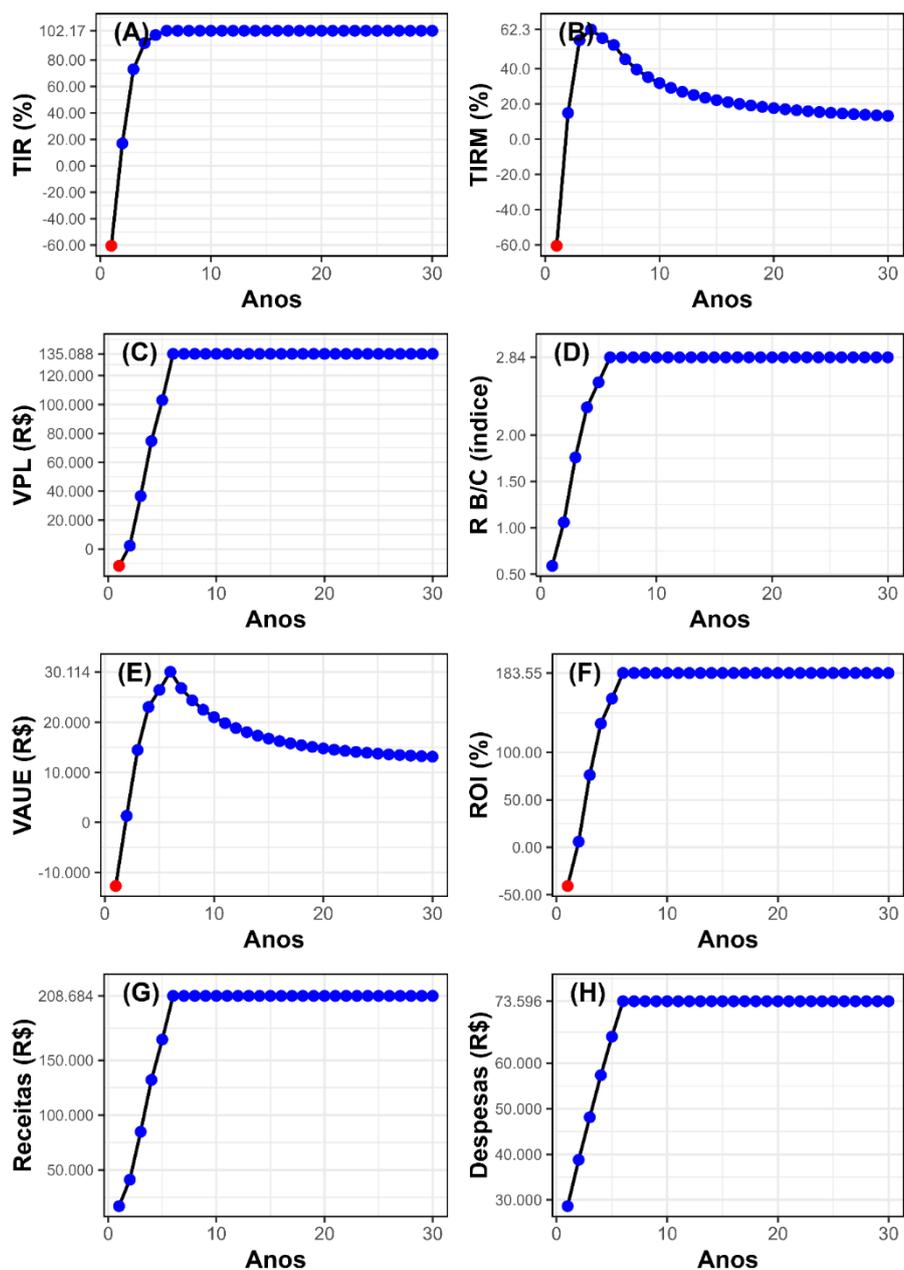
Figure 14. Economic and financial feasibility analysis for Property T7, municipality of Alegre, Espírito Santo, Brazil, over a 30-year horizon: (A) Internal Rate of Return (IRR); (B) Modified Internal Rate of Return (MIRR); (C) Net Present Value - NPV (R$); (D) Benefit/Cost Ratio (B/C); (E) Uniform Annual Equivalent Value - VAUE (R$); (F) Return on Investment - ROI (%); (G) Total Revenue (R$); (H) Total Expenses (R$). Source: prepared by the authors (2025).

Cash flow analysis reveals the basis for this exceptional performance. Revenues show meteoric growth, climbing from R$16,954.13 to R$208,684.14 (Figure 14-G). Notably, from the second year onwards, revenues not only exceed expenses but also establish a very wide operating margin, with expenses stabilizing at R$73,596.15 (Figure 14-H) against revenues approximately three- times higher. This dynamic highlights a highly efficient operating model, with strict cost control and robust production capacity.

In summary, the results attest that Property 7 is a case of financial excellence within the scope of the agroforestry systems studied. The combination of accelerated return on capital, profitability indicators that reach exceptional levels, and the generation of robust cash flow positions this venture as a benchmark for economic success, serving as a reference for the other cases in the study.

The economic feasibility of SAFs with Arabica coffee is often assessed using indicators such as Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Family Labor Remuneration (FLR) (Oliveira et al. 2010; Rahmawaty et al. 2024). Positive values in these indicators demonstrate the attractiveness of the investment

25 Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

(Oliveira et al. 2010). An agroforestry system in Acre that combines rubber trees, Catuaí coffee (*Coffea arabica*), bananas, and flemingia demonstrated financial viability with a NPV of R$ 4,558.20 for an 18-year period, a BCR of 1.33 (indicating a return of R$ 1.33 for every R$ 1.00 invested), and an RMOF of R$ 43.50, significantly higher than the opportunity cost of labor in the region (R$ 25.00) (Oliveira et al. 2010). Other studies corroborate this perspective, such as the analysis of Arabica coffee intercropping with bananas and native trees in Minas Gerais, which also revealed economic viability (Alves et al. 2015).

Crop diversification within SAFs is a central pillar for stability and increased income. Components such as fruit trees (banana, avocado, peach palm) and timber species (rubber, teak, cedar) provide additional products, cushioning implementation costs with short-cycle crops in the early years and ensuring a more regular cash flow over time (Oliveira et al. 2010; Silva et al. 2022). This strategy not only optimizes land use, allowing for higher production per area and better labor returns, but also offers security in periods of low coffee prices, contributing to environmental stability and food sovereignty for family farmers (Hernández 2021).

The quality of coffee produced in SAFs is a determining factor for their profitability. The moderate shade provided by the trees creates an ideal microclimate, positively influencing the maturation of the beans and resulting in a higher quality beverage with a smoother flavor, which allows for reaching niche markets and higher prices (Silva et al. 2022). In addition, obtaining certifications such as *Rainforest Alliance* and Regenagri, which attest to good management and sustainability practices, adds value to the product and reinforces market recognition, strengthening the position of producers and encouraging the continuity of these activities (Teixeira 2024).

Despite the obvious benefits, the implementation of SAFs with Arabica coffee presents challenges. The long period required for the development of tree species can delay the initial financial return (Teixeira 2024). In addition, SAF management requires higher management demands and specialized technical assistance, with additional costs related to pruning and organic fertilization in some arrangements, which can be a limiting factor for family farming (Siqueira et al. 2020; Hernández 2021). The agronomic productivity of coffee in SAFs may, in some cases, be lower than in monocultures if management is not properly optimized, highlighting the need for prior agronomic and economic planning, with careful selection of compatible species (Oliveira et al. 2010). Therefore, technical and governmental incentives, combined with continuous research and the dissemination of knowledge, are crucial for the full realization of the potential of SAFs in Arabica coffee farming (Oliveira et al. 2010; Hernández 2021).

Conclusions

The integrated analysis of the results of this dissertation categorically demonstrates the economic and financial viability of Agroforestry Systems (SAFs) with Arabica coffee in the Caparaó Capixaba region, consolidating them as a superior and sustainable alternative to conventional monoculture models.

The financial indicators calculated for a 30-year horizon reveal a consistent pattern: after an initial investment period (2-4 years), characterized by negative NPV and IRR – common in medium- and long-term agricultural investments – all SAFs studied achieved robust and sustainable levels of profitability. The financial turnaround, marked by positive NPV and a Benefit/Cost (B/C) ratio greater than 1, occurred remarkably quickly on some properties (T4 and T7 achieved payback in the second year), stabilizing from the sixth year onwards.

In addition to profitability, SAFs demonstrated fundamental strategic advantages:

1. Economic resilience: diversification of production (coffee, bananas, palm hearts, native fruits) created multiple sources of income, cushioning price fluctuations for any of the products and ensuring a more stable cash flow, as reported by producers and confirmed by revenue analysis.
2. Environmental sustainability and quality of life: qualitative research has shown that producers value the improvement in quality of life and consistency with the conservation of the Atlantic Forest, intangible aspects that, added to the tangible benefits of soil and microclimate improvement, add immeasurable value to the model.

26

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

3. Compliance with public policies: the success of properties linked to the Reflorestar program, with marketing channels via PNAE and PAA, demonstrates that SAFs are an effective model for reconciling environmental incentive policies with income generation for family farming.

However, the study also identified critical challenges for optimizing SAFs. The choice of coffee varieties proved crucial; more rustic varieties such as Arara provided better economic returns due to lower input requirements, while varieties such as Catucaí 785/15, requiring intensive management, increased production costs. Similarly, the selection of intercropped species must consider marketing logistics, as in the case of uvaia, which is extremely perishable, and long-term agronomic viability, such as the need for frequent replanting of some banana varieties.

Finally, SAFs represent an economically viable, environmentally regenerative, and socially just model for coffee farming in Caparaó Espírito-Santense. Their full potential depends on rigorous technical planning in the choice of species (vegetables and coffee trees), access to continuous specialized technical assistance, and the strengthening of marketing channels for diversified products. This study thus provides a solid basis for decision-making by producers and policymakers, guiding the transition to agri-food systems that are truly resilient to climate change.

Bibliographic References

Alves, Elaine Ponciano, Márcio Lopes da Silva, Sílvio Nolasco de Oliveira Neto, Tatiana Pires Barrella, and Ricardo Henrique Silva Santos. 2015. "Economic Analysis of a Coffee-Banana System of a Family-Based Agriculture at the Atlantic Forest Zone, Brazil." *Ciência e Agrotecnologia* 39: 232–39. https://doi.org/10.1590/S1413-70542015000300004.

Camargo, Giseli Mendonça, Madalena Maria Schlindwein, Milton Parron Padovan, and Luciana Ferreira da Silva. 2019. "BIODIVERSE AGROFOREST SYSTEMS: AN ALTERNATIVE FOR SMALL RURAL PROPERTIES." *Brazilian Journal of Regional Management and Development* 15 (1): 1. https://www.rbgdr.net/revista/index.php/rbgdr/article/view/4318.

Cassamo, Crimildo T., David Draper, Maria M. Romeiras, et al. 2023. "Impact of Climate Changes in the Suitable Areas for Coffea Arabica L. Production in Mozambique: Agroforestry as an Alternative Management System to Strengthen Crop Sustainability." *Agriculture, Ecosystems & Environment* 346 (April): 108341. https://doi.org/10.1016/j.agee.2022.108341.

Cerda, Rolando, Jacques Avelino, Celia A. Harvey, Christian Gary, Philippe Tixier, and Clémentine Allinne. 2020. "Coffee agroforestry systems capable of reducing disease-induced yield and economic losses while providing multiple ecosystem services." *Crop Protection* 134 (August): 105149. https://doi.org/10.1016/j.cropro.2020.105149.

Craparo, A. C. W., P. J. A. Van Asten, P. Läderach, L. T. P. Jassogne, and S. W. Grab. 2015. *"Coffea arabica* yields decline in Tanzania due to climate change: Global implications." *Agricultural and Forest Meteorology* 207 (July): 1–10. https://doi.org/10.1016/j.agrformet.2015.03.005.

Ferraz, Ibirá Ferro, Mayara Andrade Souza, Selenobaldo Axelinaldo Cabral de Sant'Anna, et al. 2024. "Financial and economic viability of agroforestry production systems: an integrative review." *OBSERVATÓRIO DE LA ECONOMÍA LATINOAMERICANA* 22 (10): e6952–e6952. https://doi.org/10.55905/oelv22n10-006.

Gomes, L. C., F. J. J. A. Bianchi, I. M. Cardoso, R. B. A. Fernandes, E. I. Fernandes Filho, and R. P. O. Schulte. 2020. "Agroforestry systems can mitigate the impacts of climate change on coffee production: A spatially explicit assessment in Brazil." *Agriculture, Ecosystems & Environment* 294 (June): 106858. https://doi.org/10.1016/j.agee.2020.106858.

27

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Hernández, Lorena Araújo. 2021. "Beneficial environmental and socioeconomic aspects of coffee cultivation in agroforestry systems in northern Paraná." Final Course Project (Bachelor's Degree in Environmental Engineering), Federal University of Uberlândia. https://repositorio.ufu.br/handle/123456789/31800.

Lacerda, André Eduardo Biscaia, Ana Lúcia Hanisch, and Evelyn Roberta Nimmo. 2020. "Leveraging Traditional Agroforestry Practices to Support Sustainable and Agrobiodiverse Landscapes in Southern Brazil." *Land* 9 (6): 6. https://doi.org/10.3390/land9060176.

Lorençone, João Antonio, Pedro Antonio Lorençone, Lucas Eduardo Oliveira Aparecido, Guilherme Botega Torsoni, and Lucas Da Rocha Ferreira. 2023. "Impact of climate change on the suitability of Coffea arabica cultivation in Brazil in the period 2040-2080." *Revista Contemporânea* 3 (10): 17811–21. https://doi.org/10.56083/RCV3N10-063.

Merga, Wakuma, and Desalegn Alemayehu. 2019. "Effects of Climate Change on Global Arabica Coffee (Coffea arabica L) Production." *Greener Journal of Plant breeding and Crop Science* 7 (1): 23–30. https://doi.org/10.15580/GJPBCS.2019.1.072319143.

MV Gestão Integrada. 2023. "About | MV Gestão Integrada." MV Gestão Integrada, September 5. https://mvgi.com.br/sobre/.

Oliveira, T. K., C. P. Sá, T. C. Oliveira, and S. A. Luz. 2010. *Characterization of two agroforestry consortium models, technical indices, and financial viability indicators. - Embrapa Portal.* Research and Development Bulletin 45. Embrapa Acre. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/976401/caracterizacao-de-dois-modelos-de-consorcios-agroflorestais-indices-tecnicos-e-indicadores-de-viabilidade-financeira.

Ovalle-Rivera, Oriana, Peter Läderach, Christian Bunn, Michael Obersteiner, and Götz Schroth. 2015. "Projected Shifts in Coffea Arabica Suitability among Major Global Producing Regions Due to Climate Change." *PLOS ONE* 10 (4): e0124155. https://doi.org/10.1371/journal.pone.0124155.

Rahmawaty, I Amelia, A Rauf, M H Ismail, and S Gandaseca. 2024. "Profitability of coffee-based agroforestry system to support farmers' income in Toba Regency, North Sumatra Province, Indonesia." *IOP Conference Series: Earth and Environmental Science* 1352 (1): 012041. https://doi.org/10.1088/1755-1315/1352/1/012041.

Richetti, Alceu, Ivo de Sá Motta, and Milton Parron Padovan. 2011. "10566 - Economic viability of agroecological vegetable production in the Integrated and Sustainable Agroecological Production System (PAIS) in Juti, Mato Grosso do Sul." *Agroecology Notebooks [Volumes 1 (2006) to 12 (2017)]* 6 (2): 2. https://aba-agroecologia.org.br/revista/cad/article/view/10566.

SENAR. 2017. *Agroforestry Systems (SAFs): concepts and practices for implementation in the Amazon biome.* National Learning Service (SENAR).

Silva, João Marcos Verly De Oliveira Da, Maurício Novaes Souza, Otacílio José Passos Rangel, et al. 2022. "Agroforestry systems and consortia in coffee cultivation." In *Topics in the recovery of degraded areas Vol. 4,*[1st] ed., organized by Maurício Novaes Souza. Mérida Publishers. https://doi.org/10.4322/mp.978-65-84548-10-7.c6.

Siqueira, Haloysio Mechelli De, Davi Salgado De Senna, João Batista Da Silva Araújo, Matheus Wandermurem Da Silva, and Erica Rodrigues Munaro Gabrig Turbay. 2020. "Economic analysis of conilon coffee plantations with perennial and forest species in southern Espírito Santo." *Revista Brasileira de Agroecologia* 15 (5): 14. https://doi.org/10.33240/rba.v15i5.23125.

Tavares, Priscila da Silva, Angélica Giarolla, Sin Chan Chou, Adan Juliano de Paula Silva, and André de Arruda Lyra. 2018. "Climate Change Impact on the Potential Yield of Arabica Coffee in Southeast Brazil." *Regional Environmental Change* 18 (3): 873–83. https://doi.org/10.1007/s10113-017-1236-z.

28

Economic Feasibility of Agroforestry Systems with Arabica Coffee in the Caparaó Capixaba Microregion, Southern Espírito Santo

Rodrigo Leonardo de Paula Dias Mendonça, Luiz Fernando de Sousa Antunes, César Otaviano Penna Júnior, Maurício Novaes Souza

Teixeira, Aline Kroner Bresciani. 2024. "Agroforestry system with coffee cultivation at Fazenda Ouro Verde, Unaí - MG." Final Course Project (Agronomy), Federal University of Rio Grande do Sul. https://lume.ufrgs.br/handle/10183/282783.

Toledo, Víctor M., and Patricia Moguel. 2012. "Coffee and Sustainability: The Multiple Values of Traditional Shaded Coffee." *Journal of Sustainable Agriculture*, March 1. world. https://www.tandfonline.com/doi/abs/10.1080/10440046.2011.583719.

Wagner, Sigrun, Laurence Jassogne, Elizabeth Price, Martin Jones, and Richard Preziosi. 2021. "Impact of Climate Change on the Production of Coffea Arabica at Mt. Kilimanjaro, Tanzania." *Agriculture* 11 (1): 53. https://doi.org/10.3390/agriculture11010053.

Zaro, Geovanna C., Paulo H. Caramori, George M. Yada Junior, et al. 2020. "Carbon Sequestration in an Agroforestry System of Coffee with Rubber Trees Compared to Open-Grown Coffee in Southern Brazil." *Agroforestry Systems* 94 (3): 799–809. https://doi.org/10.1007/s10457-019-00450-z.