

COST-BENEFIT ANALYSIS OF CLIMATE CHANGE MITIGATION AND ADAPTATION MEASURES: A CASE STUDY OF THREE DAIRY PRODUCTION FARMS IN COSTA RICA

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Abstract. Climate change was historically attributed to natural causes; however, since the Industrial Revolution, anthropogenic activities have become established as the main source of greenhouse gas (GHG) emissions. In Costa Rica, this issue is exacerbated by the high dependence on hydrocarbons and the persistence of agricultural and livestock practices with low environmental performance, which highlights the need to implement comprehensive mitigation and adaptation strategies oriented toward environmental and productive sustainability. The present study was developed based on workshops within the framework of the Low-Carbon Livestock Development Strategy (EDGBC), through which mitigation and adaptation measures were weighted in three dairy farms, as well as a cost-benefit analysis of their implementation. Two scenarios were analyzed, with and without investments associated with Nationally Appropriate Mitigation Actions (NAMA), using financial indicators such as net present value (NPV), internal rate of return (IRR), cost-benefit ratio (C/B), net profit m (NPM), return on investment (ROI), and investment payback period (IPP). The results show positive financial indicators across all scenarios. NPV values are higher in scenarios with NAMA investments, while IRR, C/B ratio, and ROI are relatively higher in scenarios without such investments. Additionally, scenarios with investments show better performance in terms of NPM and an IPP of less than one year. In conclusion, the implementation of mitigation and adaptation strategies in the case of the three farms under study strengthens competitiveness, promotes sustainability, and supports the transition to a more efficient, low-carbon, and environmentally responsible production model.

Keywords: global warming, sustainability, production, agribusiness, cost-benefit analysis

INTRODUCTION

Before the last part of the 20th century, climate change was mainly explained by natural causes, such as variations in solar activity, volcanic eruptions, and the melting of the cryosphere. However, since the Industrial

Revolution, the human population has experienced rapid growth, which led to increased consumption of fossil fuels (Ting and Vassel-Be-Hagh, 2022).

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Climate change refers to alterations in the climate caused directly or indirectly by human activities, which modify the composition of the atmosphere beyond natural variability (United Nations, 1992). The main precursor sources are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), known as Greenhouse Gases (GHG) (Ahmed, 2020). This phenomenon directly affects the agricultural sector, mainly through prolonged droughts that threaten food security. Additionally, the global food system generates about one third of total greenhouse gas emissions, with agriculture being a major source of methane and nitrous oxide (Brewer, 2023).

Costa Rica stands out as a country highly dependent on hydrocarbons, particularly for transportation and mobility (oil and natural gas), as well as its agricultural production using non-environmentally friendly practices, such as the use of agrochemicals and limited treatment of water. In addition, the use of water resource sources has grown because of the concessions granted and the relationship between demand and production in some areas of the country (Chacón Araya, 2024).

On the other hand, according to the National Inventory of Emissions by Sources and Removals by Sinks of GHG Costa Rica 1990–2017, enteric fermentation accounted for slightly more than 62.3% of CO₂ equivalent associated with the digestive process of ruminants. In this process, microorganisms break down complex carbohydrates into simpler molecules that facilitate digestion and generate CH₄ (Ministerio..., 2021).

Measures for adapting to and mitigating climate change are essential for reducing environmental, social, and productive vulnerability, while strengthening the sustainability and resilience of socio-ecological systems. These actions include sustainable practices such as efficient water management, soil conservation, and production diversification, which support the achievement of the Sustainable Development Goals (SDGs). Additionally, environmental education, community collaboration, technological innovation, and strong public policies are key to implementing these strategies effectively (León Ruedas and Perdomo Useche, 2024).

In this context, the present research aims to determine the cost-benefit relationship of fresh cheese and yogurt production in three dairy farms in Costa Rica under a conventional production system and one that incorporates environmental mitigation and adaptation measures.

THEORETICAL FRAMEWORK

Climate change exerts significant adverse impacts on strategic sectors such as agriculture, industry, public health, and biodiversity, with direct effects on the economy, social well-being, and ecosystem stability. In the agricultural sphere, the intensification of extreme climate events alters the availability and management of water resources, reduces productivity and yield stability, and worsens food insecurity on both the local and regional scale. In parallel, the livestock sector constitutes a relevant source of greenhouse gas (GHG) emissions, mainly derived from enteric fermentation, manure management, the use of synthetic fertilizers, and its indirect contribution to deforestation processes and land-use change (Galindo et al., 2022).

Likewise, climate change represents a growing challenge for public health due to its increasing the incidence of climate-sensitive diseases and antimicrobial resistance. Across all sectors, infrastructure, economy, and tourism are affected by environmental degradation, deforestation, natural disasters, and the greater frequency and intensity of extreme climate phenomena (Raihan, 2023).

The Intergovernmental Panel on Climate Change (IPCC, 2025) defines mitigation as the set of interventions aimed at reducing or limiting GHG emissions, mainly in sectors such as energy, transport, industry, forestry, and agriculture. For its part, adaptation encompasses actions aimed at reducing vulnerability and strengthening the resilience of socioeconomic and environmental systems. These cover areas such as agriculture, tourism, health, water management, urban planning, and ecosystem conservation (Martínez Sánchez et al., 2024).

Mitigation strategies have historically been driven by multilateral agreements and international regulatory frameworks, while adaptation strategies have gained relevance through private, local, and community initiatives, given their territorial and contextual nature. Since the first systematic studies on climate change in the early 1990s, the need to establish international institutions capable of preventing environmental conflicts derived from human activities has been recognized, which in turn led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC) and its associated protocols (World Bank, 2023).

Subsequently, climate policies were strengthened in low- and middle-income countries by the outcome of the Copenhagen Convention in 2009 and, in a more consolidated form, with the adoption of the Paris Agreement in 2015. These policies have focused particularly on the agricultural and forestry sectors, through integrated approaches to sustainable development and decarbonization, which incorporate mechanisms such as fair pricing, climate finance, the promotion of fair transitions, and the strengthening of institutional capacities (Rozo López, 2022).

Suazo Muñoz and Sandoval Díaz (2023) analyzed the relationship between climate risk perception and the adoption of adaptation strategies by farmers in response to the effects of drought through a systematic review of 50 empirical studies. Among the main findings, they highlighted the relevance of strengthening public policies and local programs oriented toward climate change mitigation, as well as the consolidation of resilient agricultural systems. They also evidenced the multiple implications of drought, among which impacts on crops and livestock, environmental degradation, and increased economic stress stand out. Among the main adaptation measures identified are productive diversification, the use of resilient species, and the implementation of fast-growing crops.

Herrador Valencia and Paredes (2016) analyzed farmers' perceptions and adaptation strategies to climate change in the Ecuadorian Andes region, using participatory methodologies such as focus groups, workshops, structured and semi-structured surveys. Their results showed the adoption of both individual and collective strategies, among which adaptation to variability in precipitation patterns, crop rotation, and the implementation of irrigation systems are significant. In addition, they emphasized the importance of understanding the socioeconomic and territorial context for the design and implementation of efficient support programs, as well as strengthening local organization and timely access to climate information.

For his part, Quiñones López (2023) quantified the application of strategies aimed at reducing the Ecological Footprint (EF) through Life Cycle Assessment (LCA) in the production and distribution of vegetables in the Metropolitan Region of Chile. Among the main results identified are practices such as organic production, the reduction of transport distances, improved productive performance, and decreased use of agrochemicals.

This allowed a minimum reduction of 25% in the EF to be achieved when complementing these strategies.

In the livestock field, Blanco Penedo et al. (2020) conducted a review of scientific literature to evaluate the impact of climate change on animal health and welfare, as well as the adaptive capacity of livestock systems and opportunities for the implementation of new strategies. The authors established a direct relationship between the intensification of extreme climate events and variability in nutrient availability, forage seasonality, and challenges associated with health management and disease spread.

Similarly, Jiménez Ferrer et al. (2015), in their analysis of advances in measures mitigating and adapting to climate change in the livestock sector, highlighted the importance of implementing agroforestry systems, good livestock practices (GLP), silvopastoral schemes, and animal diets based on local arboreal forage resources. These strategies present high potential for carbon sequestration and the mitigation of GHG emissions, depending on the configuration and management of the production system.

In an applied approach, García et al. (2018) developed participatory workshops with individuals associated with milk collection and cooling centers, through which productive practices were prioritized and evaluated based on criteria of productivity, adaptation, and mitigation. Subsequently, an economic analysis was carried out using financial indicators such as net present value (NPV), internal rate of return (IRR), and the cost-benefit ratio (C/B), evidencing the economic viability of the selected practices.

Likewise, Jaime Peña and López Guillén (2023), through a financial analysis, identified the costs and benefits associated with five sustainable livestock projects. Their results indicated that private evaluation is not cost-effective when the opportunity costs of the beneficiaries are not considered; however, when all relevant income and costs of the actors involved are incorporated into the cost-benefit analysis, the projects remain cost-effective and generate economic, social, and environmental benefits to varying degrees.

Finally, Suárez et al. (2016) evaluated the benefits and costs of various adaptation measures linked to the forestry, livestock, and water resource management sectors, using indicators such as NPV, BC/BR ratio, and internal rate of return (IRR). Their results showed cost-benefit ratios greater than one and competitive internal

rates of return for all measures analyzed. This provides evidence of their economic convenience and their contribution to strengthening these sectors.

MATERIAL AND METHODS

An analysis of the measures implemented by producers was conducted through a systematic and comprehensive literature review, drawing on both primary and secondary sources from databases such as SpringerLink, SciELO, ScienceDirect, and ProQuest. The aim was to identify environmentally impactful practices adopted in dairy production systems in Costa Rica, in alignment with the Nationally Appropriate Mitigation Actions (NAMA).

Subsequently, field visits were conducted to three farms primarily dedicated to the production of fresh cheese and yogurt, with the purpose being to identify the environmental mitigation strategies implemented and describe them by assigning a level of compliance in accordance with the guidelines established in the NAMA technical manual. The farms were selected by convenience, with the chosen producers meeting at least one of the NAMA practices. This selection was carried out through contacts with the National Institute of Agricultural Innovation and Technology Transfer (INTA) and the National Chamber of Milk Producers (Proleche).

The weighting of the measures implemented on each farm was carried out based on the methodology proposed by the Ministry of Agriculture and Livestock (MAG), incorporating expert judgments for assigning scores and prioritizing those strategies with a greater potential impact and lower implementation costs (Ministerio de Agricultura y Ganadería [MAG], 2016). The potential of each measure was evaluated using an ordinal scale from 1 to 5, where a value of 1 represents null or marginal potential, and a value of 5 corresponds to high mitigation potential. This process was carried out within the framework of participatory workshops of the Low-Carbon Livestock Development Strategy (EDGBC).

For the final weighting, relative weights of 25% were assigned to mitigation potential, 15% to the impact on productivity, 15% to adaptation potential, and 45% to the level of application of the strategy. Additionally, a dichotomous weighting factor was incorporated for the effective application of the measure, assigning

a value of 0 when the strategy is not implemented and a value of 1 when the farm applies it.

The cost-benefit analysis incorporated the initial investment and operating costs with the objective of estimating the net present value (NPV) of the projected cash flows over the evaluation horizon. To this end, the instrument used was a survey applied to producers, which was divided into three sections: personal data; production data in relation to mitigation and adaptation measures with their respective costs; data based on cheese and yogurt production.

Subsequently, through field visits and virtual meetings with participating producers, information related to yield levels, sales volumes, and cost structure was collected. The data obtained were systematized and complemented with information from invoices, accounting records, and other supporting documents (Aguilera, 2017).

Based on this information, the individual cost structure for each producer was prepared and the projected net cash flows were constructed over a five-year horizon. In the base year (year 0), the initial investments associated with the implementation of environmental mitigation and adaptation strategies were incorporated, as well as those made at the beginning of the project. Investments made prior to the analysis period were considered through the recognition of the corresponding depreciation.

Annual production costs and average sales were adjusted for inflation, applying a rate of 2.45%, estimated using an ARIMA (2,2,2) model with data from the Consumer Price Index (CPI) of Costa Rica from 1960 to 2024 (BCCR, 2024a).

The salvage value was calculated taking into consideration the residual value of assets not fully depreciated during the evaluation period. Depreciation was estimated using the straight-line method with respect to useful lives (SCIJ, 1988). On the other hand, for working capital, the lag method was applied, considering a one-week delay over a 365-day operating horizon.

Using Yahoo!Finance (2024) and Damodaran (2024), the following reference values were determined: the historical yield of U.S. Treasury bonds (4.86%), the S&P 500 index (11.66%), the unlevered return of the reference dairy company (-0.96%), and country risk (6.58%). The above was used to obtain a cost of capital of 11.37%.

The cost of capital or minimum expected return by the investor was determined using the formula presented below (Damodaran, 2024).

$$K_e = R_f + B_{unlevered}(K_m - R_f) + R_p \quad (1)$$

where:

R_f – is the historical return of US Treasury bonds.

K_m – is the historical return of the US stock index.

$B_{unlevered}$ – unlevered benchmark company return.

R_p – country risk value.

The cost-benefit relationship was determined using the following equation (Aguilera, 2017):

$$CB = \frac{NPV}{I_0} \quad (2)$$

where:

NPV – net present value.

I_0 – is the value of the initial investment outlay.

and the net present value (NPV) was calculated using the formula below (Aguilera, 2017):

$$NPV = \sum_{t=1}^n \frac{V_t}{(1+k)^t} - I_0 \quad (3)$$

where:

V_t – is the cash flow in each period t .

I_0 – is the value of the initial investment outlay.

n – is the number of periods considered.

k – is the project's discount rate.

Based on the cost structure and the projected net cash flows, both scenarios were evaluated (with and without investments associated with the Nationally Appropriate Mitigation Actions [NAMA]) to estimate the main financial indicators and measure the profitability of the strategies implemented. For this analysis, a sales price adjusted with a 13% increase was considered, in accordance with the proposal made by Zamora Mendieta et al. (2025).

First, the net profit margin (NPM) was used to estimate the proportion of each monetary unit (of sales revenue) that remains as net profit after deducting all operating costs, administrative expenses, taxes, interest, and other financial obligations. In this sense, higher values for this indicator reflect better financial performance and greater efficiency in cost management (Gitman and Zutter, 2012).

The internal rate of return (IRR) is defined as the discount rate that sets the net present value (NPV) of an investment project equal to zero, representing the implicit rate of return that the firm would obtain by investing in the project and receiving the expected cash inflows over the evaluation horizon (Gitman and Zutter, 2012).

For its part, the return on investment (ROI) made it possible to measure the relative profitability of a specific investment or activity within the project, taking account of the relationship between the capital invested and the net profits generated (Andrade Pinelo, 2011). Complementarily, the investment payback period (IPP) was used to estimate the time required to recover the initial investment through the cash flow generated by the project, constituting a relevant indicator of liquidity and risk (Gitman and Zutter, 2012).

Finally, to facilitate the interpretation and comparability of the results, all monetary values were expressed in U.S. dollars. The conversion was carried out using the official exchange rate published by the Central Bank of Costa Rica as of September 30, 2024, equivalent to ₡522.87 per U.S. dollar (BCCR, 2024b).

RESULTS

When analyzing the environmental mitigation and adaptation measures implemented on the farms under study, detailed and specific information was collected for each production unit. Producer A, located in Pacayas de Cartago, manages a 14-hectare farm dedicated to the production and commercialization of semi-hard fresh cheese. The production system maintains an average of 25 Jersey cows in milk throughout the year. In terms of resource use, the water used for washing the milking equipment comes from public service, while the water used for cleaning the sheds is obtained through harvesting rainwater, which is subsequently stored in tanks. Regarding energy use, the farm has a solar thermal energy system through solar panels intended to heat the water used both for sanitizing the milking equipment and for preparing the milk supplied to calves.

Producer B, located in San Pablo de Oreamuno in the province of Cartago, has a 3.5-hectare farm dedicated to the production and commercialization of semi-hard fresh cheese and butter. The production system is based on grazing, with an average of 11 Jersey cows in milk. The water supply for productive activities comes from the Communal Association for the Administration

of Water Supply and Sewerage Systems (ASADA). Additionally, water stored from a nearby river is used for cleaning the facilities and for fertigation of the paddocks, optimizing the use of water resources.

Producer C, located in Guápiles in the province of Limón, manages a 10-hectare farm under a grazing system, with an average of 26 animals of the Jersey, Brown Swiss, and Dairy Gyr breeds which produce various dairy products. The water resource for productive tasks comes mainly from nearby springs and streams, while the water specifically used in the processing of dairy products is supplied by public services.

In general, the farms analyzed implement at least one environmental mitigation strategy classified within the framework of the Nationally Appropriate Mitigation Actions (NAMA). Likewise, in the productive planning of each unit, additional environmental mitigation and adaptation measures in the process of implementation are identified. Table 1 systematically presents the NAMA measures currently implemented by the producers participating in the study.

Regarding the first NAMA measure, corresponding to rational grazing, Farm A has 41 paddocks of approximately 3500 m², delimited with electric fencing and with a one-day rotation period. In addition, it has a main diversion channel that helps prevent soil erosion.

Farm B has slopes between 30% to 40% and has therefore implemented soil conservation measures in coordination with the Ministry of Agriculture and Livestock (MAG). It has 31 paddocks of approximately 1447 m²,

designed according to contour lines and with an average rotation of 0.75 days. It also has diversion channels and promotes the conservation of native trees, avoiding the use of agrochemicals. For its part, Farm C has 28 paddocks distributed across 10 hectares, with a daily rotation system. The property has four small water bodies that facilitate livestock access to water resources.

Regarding pasture improvement, Farm A maintains species of high nutritional and edaphic value, such as Kikuyo and African Star grass. In addition, it has 2800 m² of black sorghum and 200 m² of Mexican sunflower used as forage banks. Similarly, Farm B mainly has Kikuyo grass in its paddocks and 1153 m² of ryegrass, used as a pasture bank during periods of low regeneration. Although it currently does not have forage banks, it is in the process of implementing these in coordination with the MAG. In Farm C, Mombasa and Retana grasses predominate, distributed among the different paddocks, as well as 1930 m² of Taiwan grass for livestock feeding as complementary forage.

With respect to the implementation of live fences, Farm A does not use this system, although it has established trees along its 2300-meter perimeter, with no record of the planting date or the species planted. Farm B also does not have live fences, but it has carried out reforestation actions in areas near the river and conserves 0.43 hectares of forest dedicated to environmental preservation. In addition, it will soon participate in an evaluation process for the implementation of this system. On the other hand, Farm C does have live fences both along

Table 1. NAMA measures implemented by the study producers

NAMA measurement	Measurement details	Producer A	Producer B	Producer C
Rational grazing	Number of paddocks	41	31	28
	Rotation intervals (days)	1	0.5–1	1
Pasture improvement	Species	Estrella africana and Kikuyo	Ray Grass and Kikuyo	Mombaza and Retana
Live fences	Linear meters	2 300	Does not have	3 058
	Species	Local species		<i>Erythrina poeppigiana</i> (poró) and <i>Gliricidia sepium</i> (madero negro)
Improvements in fertilization plans	Measure	Rainwater harvesting	Collection of whey and water used to wash the shed	Solid separator and fertigation
		Solid separator and fertigation		Whey collection

Source: own elaboration.

the perimeter and in the division of paddocks, which consists of Poró and Madero Negro trees. It contains approximately 2 hectares of forest dedicated to environmental preservation and mitigation.

Regarding fertilization plans, Farm A has a tank and five ponds located in a shed to collect rainwater. The system includes pipelines and a solid separator, which allows the filtered water to be used in fertigation and the solid residues as fertilizer. Animal waste is also used as organic fertilizer. Farm B collects water from the shed and the liquids generated in the cheese plant, which are used through gravity irrigation in the paddocks located in the lower areas of the land. Finally, Farm C uses a slurry system to collect milking waste. This is applied as liquid fertilizer in fertigation, while solid residues are distributed as organic fertilizer in trees and pastures.

It is important to note that all three producers implement genetic improvement practices, with the aim of increasing productive yields and obtaining animals better adapted to the conditions of each area.

Thus, Table 2 presented below shows the weighting, where it is observed that only one producer fully complies with the implementation of environmental mitigation strategies, while the other producers have room for improvement.

On the other hand, the production costs per kilogram of fresh cheese and per liter of yogurt were determined for each of the producers (Table 3). The cost per liter of milk was considered based on the costs associated with production and the annual production quantities, resulting in a cost of \$0.75/L for producer A, \$0.89/L for producer B, and \$0.96/L for producer C.

Based on the above, it was estimated that the production cost of one kilogram of fresh cheese for Producer A is \$1.54/kg and for Producer B it is \$2.11/kg. Although the costs shown in the tables for both producers are similar, the main difference in the cost per kilogram of fresh cheese is due to the amount of milk required, as well as the quantity of milk obtained daily. Along the same lines, the production cost of one liter of yogurt is \$2.42/kg, with milk being the main cost component for yogurt production.

The investment allocated to the implementation of mitigation and adaptation strategies was determined for the three case studies. Producer A made a total investment of \$11 484.79, which encompasses the installation of solar panels, fences, posts, energizers, wires, insulators, slurry systems, a grass cutter, and forage seed. Producer B allocated \$7943.44 to the implementation of posts, fences, tanks, irrigation systems, wires,

Table 2. Characterization of NAMA measures implemented by the study producers

Farm	Measure	Mitigation Potential	Impact on Productivity	Adaptation Potential	Implements	Weighting
A	Rational grazing	4.00	5.00	1.00	1.00	2.35
	Pasture improvement	4.00	5.00	1.00	1.00	2.35
	Living fences	3.00	1.00	1.00	0.00	1.05
	Improved fertilization plans	2.00	1.00	1.00	1.00	1.25
B	Rational grazing	4.00	5.00	1.00	1.00	2.35
	Pasture improvement	4.00	5.00	1.00	1.00	2.35
	Living fences	3.00	1.00	1.00	0.00	1.05
	Improved fertilization plans	2.00	1.00	1.00	1.00	1.25
C	Rational grazing	4.00	5.00	1.00	1.00	2.35
	Pasture improvement	4.00	5.00	1.00	1.00	2.35
	Living fences	3.00	1.00	1.00	1.00	1.50
	Improved fertilization plans	2.00	1.00	1.00	1.00	1.25

Source: own elaboration.

Table 3. Annual cost in \$USD of fresh cheese and yogurt production for the producers in the study

Category	Annual Cost (\$USD)		
	Producer A (fresh cheese)	Producer B (fresh cheese)	Producer C (yogurt)
Production Inputs	11 655.92	7 545.04	11 019.49
Raw Materials and Others	11 609.17	7 287.30	8 754.30
Packaging	46.75	257.75	2 265.19
Labor	4 789.96	4 789.96	1 995.82
Other	593.80	2 685.49	4 339.17
Services	380.94	1 206.65	2 168.80
Cleaning Supplies	77.36	460.08	1 216.97
Equipment Depreciation	135.49	1 018.77	953.40
Subtotal	17 039.68	15 020.50	17 354.47
Other unforeseen events (2.50%)	14.84	67.14	108.48
Total	17 054.52	15 087.64	17 462.95

Source: own elaboration.

insulators, energizers, land preparation, and grass seed. Producer C invested \$12 699.60 in a slurry system, improved pasture, posts, grass chopper, energizer, fences, wires, and insulators.

Overall, the largest investment items among the three producers correspond to the installation of fences, slurry systems, and pasture improvement. Thus, the results of the net cash flow of the three producers are presented below (Table 4).

Table 4. Net cash flow in \$USD of the producers under study

Year	Net cash flow (\$USD)		
	Producer A	Producer B	Producer C
2024	12 192.23	8 709.73	25 385.00
2025	62 761.93	28 124.93	14 043.22
2026	64 241.86	29 379.27	14 555.72
2027	65 765.85	31 422.55	14 781.50
2028	67 327.15	32 861.11	15 169.30
2029	93 505.92	101 993.44	59 617.16

Source: own elaboration.

Subsequently, using the net cash flow results, the financial indicators and ratios for each producer were obtained (Table 5).

According to the scenarios evaluated (with and without investment in NAMA strategies), positive values were obtained for both net present value (NPV) and internal rate of return (IRR), indicating that in all cases the invested capital is recovered and that the projects generate additional economic value beyond the initial investment. However, the scenarios that incorporate investments in environmental mitigation and adaptation strategies present higher NPV values, which is explained by the 13% adjustment in the sales price.

For their part, the internal rate of return (IRR), the cost-benefit ratio (C/B), and the return on investment (ROI) recorded higher values in the scenarios without investment compared to those that include NAMA investments. Even so, the results in both scenarios are positive, demonstrating that each dollar invested is compensated and rewarded with an economic gain. It should be noted that, in the case of Producer C, the C/B ratio is influenced by the inclusion of investment in a vehicle intended for both farm and processing plant activities; therefore, the bank loan associated with this acquisition was incorporated into the analysis.

Table 5. Estimated financial indicators and ratios for the producers under study

Producer	NPV (\$USD)	IRR (%)	C/B	NPM (%)	ROI (%)	IPP
A without investment	217 654.27	7 647.00	307.67	54.00	82 251.00	0.01
A with investment	241 883.44	517.00	19.84	56.00	452.00	0.19
B without investment	132 385.78	3 209.00	172.76	36.00	2 023.00	0.03
B with investment	143 852.38	329.00	16.52	38.00	211.00	0.30
C without investment	47 921.56	88.00	3.78	34.00	94.00	0.29
C with investment	54 357.78	62.00	2.14	41.00	64.00	0.78

Source: own elaboration.

Regarding the net profit margin (NPM), it is observed that the scenarios that incorporate investments in environmental mitigation and adaptation strategies present higher values, reflecting greater efficiency in the generation of net profits. Consistent with these results, the investment payback period (IPP) was less than one year in the scenarios with investment, which evidenced rapid capital recovery and a low level of financial risk.

DISCUSSION

In the study by García et al. (2018), in the financial evaluation by farm typology, small farms showed better financial margins with an internal rate of return (IRR) of 21.6% and a cost-benefit (B/C) ratio of 1.46. This reflects higher profitability compared to medium-sized farms, which recorded an IRR of 20.7% and a B/C ratio of 1.23. This result is attributed to a better combination of Silvopastoral Good Practices (SSP), Management Good Practices (BPM), and Infrastructure Good Practices (BPI). In the financial evaluation according to the typology of practices implemented, all of them showed positive net present value (NPV). SSP presented an IRR of 20.1% and a B/C ratio of 1.3, BPM an IRR of 21.0% and a B/C ratio of 1.2, and BPI an IRR of 21.8% and a B/C ratio of 1.2. Overall, the results showed that the adoption of silvopastoral technologies contributes to greater profitability and financial sustainability in livestock farms.

Sustainable livestock projects proved to be profitable in terms of private financial returns, with an average IRR of 29%, higher than the 12% discount rate required for their financing. Among the projects in the municipalities under study, the Córdoba project shows

the highest NPV and an IRR of 33.84%, while in Arauca a lower NPV and an IRR of 24.24% are reported. However, when comparing the situation without and with the project, in some cases a positive value is not generated due to high opportunity costs or already high income from current activities. Nevertheless, when incorporating a social cost-benefit analysis that considers environmental and social benefits, all projects are profitable for society. This highlights the feasibility and profitability of implementing sustainable livestock projects in private terms with social and environmental value (Jaime Peña and López Guillén, 2023).

In the cost-benefit analysis of the livestock sector for climate change adaptation measures, practices such as improved pasture management and the implementation of water storage and irrigation systems were evaluated. In the case of improved pasture management, the economic indicators show a positive NPV in all scenarios, with a very high IRR of 216% and a cost-benefit ratio (BCR) of 2.4, under a social discount rate (SDR) of 12%. This indicates that the project is economically viable and effective in encouraging investments in the livestock sector. Likewise, water storage and irrigation systems present a positive NPV, an IRR of 36%, and a BCR between 1.39 and 1.61, demonstrating the profitability of this measure and its contribution to reducing the economic vulnerability of the livestock sector (Suárez et al., 2016).

CONCLUSIONS

In conclusion, the adoption of climate change mitigation and adaptation strategies contributes significantly to strengthening the competitiveness of the dairy sector,

reducing its vulnerability to climate impacts, and promoting a more efficient, responsible, and sustainability-oriented productive model. In this regard, the incorporation of these measures into dairy production systems is associated with strategic investments that favor both the financial performance of producers and the fulfillment of national and international commitments on sustainability and the reduction of greenhouse gas (GHG) emissions.

From the perspective of the cost structure, feed represents, on average, 33% of total milk production costs in the cases analyzed. This highlights the need to identify and implement complementary alternatives that reduce dependence on commercial concentrations and improve efficiency at the farm level.

Likewise, based on the financial and technical analysis, it is concluded that the implementation of environmental mitigation and adaptation strategies constitutes an economically viable and sustainable alternative for the three case studies of cheese and yogurt producing farms. Although some financial indicators such as the internal rate of return (IRR), the cost-benefit ratio (C/B), and the return on investment (ROI) present slightly higher values in scenarios without environmental investment, the increase in net present value (NPV) and the improvement in the net profit margin (NPM) show that investments associated with NAMA generate relevant economic benefits, in addition to contributing to the strengthening of climate resilience in the farms analyzed.

Regarding the study's limitations, identifying cheese producers complying with NAMA measures proved challenging, as the National Chamber of Milk Producers (Proleche) has no clear registry of such producers. Moreover, there was limited willingness to provide support from the Ministry of Agriculture and Livestock (MAG). This difficulty was even greater for yogurt producers. Additionally, another key limitation was the limited or non-existent record-keeping of production costs, livestock, and other relevant operational aspects.

Finally, future research should expand to other dairy by-products to support stronger economic and production decision-making, as well as the development of public policies that enhance sector competitiveness, particularly for small and medium-sized producers. Greater incorporation of farm-level production parameters is also recommended to improve yields and cost efficiency by increasing milk output and reducing waste.

Additionally, studies integrating social and environmental indicators should be promoted in order to strengthen decision-making in the implementation of mitigation and adaptation measures in livestock systems.

REFERENCES

- Ahmed, M. (2020). Introduction to Modern Climate Change. *Sci. Total Env.*, 734, 139397. <https://doi.org/10.1016/j.scitotenv.2020.139397>
- Aguilera, A. (2017). El costo-beneficio como herramienta de decisión en la inversión en actividades científicas. *Cofin Habana*, 11(2), 322–343. Retrieved from: http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2073-60612017000200022
- Andrade Pinelo, A.M. (2011). Análisis del ROA, ROE y ROI. *Contad. Empres.* Retrieved from: <http://hdl.handle.net/10757/608313>
- BCCR (Banco Central de Costa Rica). (2024a). Índice de precios al consumidor (IPC) (base diciembre 2020 = 100): Niveles y variaciones. Retrieved from: <https://gee.bccr.fi.cr/indicadoreseconomicos/cuadros/frmvercatcuadro.aspx?idioma=1&codcuadro=%202732>
- BCCR (Banco Central de Costa Rica). (2024b). Indicadores económicos de Costa Rica: Cuadro 1. Retrieved from: <https://sdd.bccr.fi.cr/es/IndicadoresEconomicos/Inicio/Contenedor/6?Cuadro=1>
- Blanco Penedo, I., Cantalapiedra, J., Llonch, P. (2020). Impacto del cambio climático sobre el bienestar animal en los sistemas ganaderos. *ITEA Inf. Técnic. Econ. Agrar.*, 116(5), 424–443. <https://doi.org/10.12706/itea.2020.028>
- Brewer, T. (2023). *Climate Change: An Interdisciplinary Introduction* (1st ed.). Springer. <https://doi.org/10.1007/978-3-031-42906-4>
- Chacón Araya, K. (2024). ¿Está en riesgo la imagen verde de Costa Rica? Programa Estado de la Nación. Retrieved from: <https://estadonacion.or.cr/esta-en-riesgo-la-imagen-verde-de-costa-rica/>
- Damodaran, A. (2024). Damodaran online. Bio and Mission. Retrieved from: https://pages.stern.nyu.edu/~adamodar/New_Home_Page/biomission.html
- Galindo Paliza, L.M., Hoffmann, B., Vogt-Schilb, A. (2022). ¿Cuánto costará lograr los objetivos del cambio climático en América Latina y el Caribe? Banco Interamericano de Desarrollo. <https://doi.org/10.18235/0004021>
- García, C., Sepúlveda, C., Gómez, M., Ibrahim, M. (2018). Identificación, priorización y análisis costo-beneficio de buenas prácticas ganaderas que los productores de fincas estratificadas implementan para reducir los efectos de la variabilidad climática en el municipio de Olanchito, Yoro,

- Honduras. *Prod. Agropec. Desarr. Sosten.*, 7, 73–97. <https://doi.org/10.5377/payds.v7i0.8429>
- Gitman, L., Zutter, C. (2012). *Principios de administración financiera* (13ª ed.). Pearson.
- Herrador Valencia, D., Paredes, M. (2016). Cambio Climático Y Agricultura De Pequeña Escala En Los Andes Ecuatorianos: Un Estudio Sobre Percepciones Locales Y Estrategias De Adaptación. *J. Latin Americ. Geogr.*, 15(2), 101–121. Retrieved from: <https://repository.lsu.edu/jlag/vol15/iss2/5/>
- Intergovernmental Panel on Climate Change (2025). Interrelación entre adaptación y mitigación. Retrieved from: https://archive.ipcc.ch/publications_and_data/ar4/wg2/es/tssts-5-2.html
- Jaime Peña, D., López Guillén, J.D. (2023). Medio ambiente y posconflicto: Análisis costo beneficio de proyectos de ganadería sostenible en municipios PDET [Trabajo de Grado]. Universidad de los Andes. Retrieved from: <https://hdl.handle.net/1992/64466>
- Jiménez Ferrer, G., Soto Pinto, L., Pérez Luna, E., Kú Vera, J.C., Ayala Burgos, A., Villanueva López, G., Alayon Gamboa, A. (2015). Ganadería y cambio climático: Avances y retos de la mitigación y la adaptación en la frontera sur de México. *Socied. Rural. Prod. Medio Ambien.*, 15(30), 55–70. Retrieved from: <https://sociedadesruralesojos.xoc.uam.mx/index.php/srpma/article/view/289>
- León Ruedas, Y., Perdomo Useche, Y.L. (2024). Revisión sistemática sobre las estrategias de permacultura en la adaptación y mitigación al cambio climático. *Gest. Ambien.*, 27(2), 113089. <https://doi.org/10.15446/ga.v27n2.113089>
- Martínez Sánchez, J.N., Himmelsbach, W., Díaz, M.I.Y., González Tagle, M., Escamilla, H.A.G. (2024). Estrategias de gestión forestal y cambio climático: Una revisión. *Rev. Mexic. Agroecosis.*, 11(2), 2. <https://doi.org/10.60158/rma.v11i2.414>
- Zamora Mendieta, D.J., Solorzano Thompson, J., Paniagua Molina, J., Viquez Ramírez, N.V. (2025). Willingness to pay for cheese and yogurt from production systems with climate change mitigation. *J. Agribus. Rural Dev.*, 3(77), 348–361. <http://dx.doi.org/10.17306/J.JARD.2025.3.00027R1>
- MAG (Ministerio de Agricultura y Ganadería). (2016). NAMA Ganadería: Ganadería bovina en Costa Rica. Retrieved from: <http://www.mag.go.cr/bibliotecavirtual/L01-10885.pdf>
- Ministerio de Ambiente y Energía & Instituto Meteorológico Nacional (2021). Inventario Nacional de emisiones por fuentes y absorción por sumideros de Gases de Efecto Invernadero. Costa Rica, 1990–2021. Retrieved from: <http://cglobal.imn.ac.cr/index.php/publications/4230/>
- Quiñones López, C.A. (2023). Evaluación ambiental de escenarios de producción y distribución de alimentos de origen agrícola en la Región Metropolitana: Caso de estudio: Hortalizas [Tesis Postgrado]. Universidad de Chile. Retrieved from: <https://repositorio.uchile.cl/handle/2250/194880>
- Raihan, A. (2023). A review of the global climate change impacts, adaptation strategies, and mitigation options in the socio-economic and environmental sectors. *J. Env. Sci. Econ.*, 2(3), 3. <https://doi.org/10.56556/jescae.v2i3.587>
- Rozo López, D.P. (2022). Cambio climático bajo los lentes de la comunidad jurídica internacional [Trabajo de investigación]. Universidad de los Andes. Retrieved from: <https://repositorio.uniandes.edu.co/entities/publication/fd98b154-b99e-4634-bdc3-91e8b39a16ca>
- SCIJ (Sistema Costarricense de Información Jurídica) (1988). Decreto Ejecutivo 18445: Reglamento a Ley del Impuesto sobre la Renta. ANEXO N° 2. Metodos y porcentajes de depreciacion. Retrieved from: https://pgrweb.go.cr/scij/Busqueda/Normativa/Normas/nrm_articulo.aspx?param1=NRA&nValor1=1&nValor2=7241&nValor3=95599&nValor5=211987&strTipM=FA
- Suárez, F., Duque, Á., Pava, M., Estupiñán, S., Calderón, S., ..., Ludeña, C.E. (2016). (Monografía No. 261). Banco Interamericano de Desarrollo <https://doi.org/10.18235/0012701>
- Suazo Muñoz, C., Sandoval Díaz, J. (2023). Revisión sistemática de la percepción de riesgo en agricultores ante la sequía: Factores de influencia, contenidos percibidos, estrategias de adaptación y prácticas asociadas. *Sci. Agropec.*, 14(1), 139–152. <https://doi.org/10.17268/sci.agropecu.2023.013>
- Ting, D.S.-K., Vassel-Be-Hagh, A. (Eds.). (2022). *Mitigating climate change: Proceedings of the Mitigating Climate Change 2021 Symposium and Industry Summit (MCC2021)*. Springer. <https://doi.org/10.1007/978-3-030-92148-4>
- United Nations (1992). United Nations Framework Convention on Climate Change. Retrieved from: <https://www.un.org/fileadmin/Documentos/BDL/2009/6907.pdf>
- World Bank (2023). Reality check: Lessons from 25 policies advancing a low-carbon future. Retrieved from: <http://hdl.handle.net/10986/40262>
- Yahoo!Finance. (2024). Fonterra Co-operative Group Limited (FCG.NZ). Retrieved from: <https://finance.yahoo.com/quote/FCG.NZ/profile/>