frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 25 June 2025
DOI 10.3389/fsufs.2025.1486272

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OPEN ACCESS

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RECEIVED 25 August 2024
ACCEPTED 30 May 2025
PUBLISHED 25 June 2025

CITATION
Wolfart SB, Elejalde DAG, Bortoluzzi SC and de Lima JD (2025) A model for selection and evaluation of investment alternatives in dairy cattle.
Front. Sustain. Food Syst. 9:1486272.
doi: 10.3389/fsufs.2025.1486272

A model for selection and evaluation of investment alternatives in dairy cattle

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In rural areas, continuous changes require managers to seek technologies to improve the property's sustainability. Thus, the present research aimed to develop a constructivist multi-criteria model for the choice of Investment Alternatives (IA) in dairy cattle for subsequent economic-financial evaluation in a rural property in Brazil. It is a case study, characterized by nature as applied, and of a descriptive character, with a qualitative and quantitative approach. The intervention instrument called Methodology Multicriteria Decision Aid Constructivist (MCDA-C) was used to develop the IA choice model for dairy cattle. Subsequently, the best IA was submitted to the economic-financial appraisal through a framework, which guided the choice of the investment evaluation methodology. The framework integrates the Expanded Multi-Index Methodology (EMIM) for deterministic situations, the Monte Carlo Simulation (MCS) in the presence of uncertainty, and the Real Options Analysis (ROA) in the existence of relevant managerial flexibilities. The main results of the MCDA-C for the choice of IA in dairy cattle was the identification of 22 Primary Assessment Elements (PAEs), which generated 29 concepts (objectives), divided into 4 Fundamental Points of View (FPV): profitability; sustainability; quality; and productivity, which unfolded in elementary points of view and the construction of 17 descriptors with ordinal and cardinal scales of measurement. Verifying the status quo made it possible to conduct global assessment of each IA. The best alternative (A3, formed by the free stall, milking robotization, and photovoltaic systems projects) reached 99.38 points, considered competitive, on a scale where 0 points (neutral level) and 100 points (good level). Next, the investment via EMIM was evaluated, which showed that this alternative has an expected return of a medium degree and a high level of sensitivity, indicating the need to use the MCS. Thus, 100,000 pseudo-random simulations were performed, indicating a low probability of financial failure in implementing A3. The research contributes to filling the gaps identified in the literature, as it integrates an MCDA-C for the choice of IA with the respective economic-financial viability analysis. It is worth mentioning that the theoretical-methodological proposal of the present study can be applied to other rural properties.

KEYWORDS

agribusiness, dairy cattle, investment alternatives, multicriteria model, MCDA-C, expanded multi-index methodology, Monte Carlo simulation, real options analysis

1 Introduction

The last few decades have been revolutionary for global agribusiness, especially due to the speed at which technologies were developed and implemented (Embrapa Empresa Brasileira de Pesquisa Agropecuária, 2022). Milk production is among the most important economic activities in the agribusiness segment, being one of the main sources of income for family farming in Brazil (Carlotto et al., 2011; Di Domenico et al., 2017). Brazil is the fifth largest milk producer in the world (Santos et al., 2019). Brazilian milk production jumped from 5.2 million tons/year to 35.5 million tons/year between 1974 and 2021, revealing sector evolution (Embrapa Empresa Brasileira de Pesquisa Agropecuária, 2022). In this context, methodologies and performance indicators are essential instruments for producers to monitor and evaluate the production process, supporting the critical analysis of results and supporting the decision-making process of the dairy activity (Ferreira et al., 2020; Elejalde et al., 2023).

In this context, among the various decisions made by rural producers, there are decisions related to the choice of viable and appropriate technologies to ensure the maintenance of the activity. However, there are many technological advances in the sector, and the need for investments now demands controls and planning of the activities carried out, managing and knowing their results (Kruger et al., 2019; Martins and Zanin, 2020; Elejalde et al., 2023).

The activity of dairy cattle (DC) farming is one of the rural activities with several technological advances and, as a result, the difficulty for rural producers in choosing and evaluating the viability of different investment alternatives (IA) can be seen. Among them, the genetic quality of the animals, acquisition of machinery and equipment, adequate infrastructure for housing the animals, milk storage capacity, and forms of commercialization can be mentioned (Marchioro, 2014; Eastwood et al., 2021; Bengtsson et al., 2022). Among these potential investment alternatives (AI) in DC are the modernization of the system production and the milking system. Despite the high investment, robotic milking presents several benefits, linked to improved quality of life for rural producers, reduced labor costs, and increased productivity (Pacassa et al., 2022; Gil et al., 2023).

Another important technology in DC is the photovoltaic solar energy system, as it also presents itself as an investment capable of improving results in DC (Altoé et al., 2017; Nespolo et al., 2022). The results obtained in economic-financial viability research show that photovoltaic systems reduce the cost of electrical energy, also resulting in a reduction in the total cost of dairy production on the property, given that the main fixed cost of the activity is the electrical energy required for the operation of machines and equipment (Vargas et al., 2019; Nespolo et al., 2022).

The generation of biogas, biofertilizer, and electrical energy, obtained through the use of waste in conjunction with biodigesters and a generator engine, also presents economic advantages for DC. The results of studies such as those by Guares et al. (2021) indicate the economic viability of the investment for almost all systems evaluated. However, viability depends on the raw material used and the installed power. Therefore, choosing the best system and minimum power is essential to ensure the economic viability of the investment. Thus, with the implementation of the biodigester, rural producers can become self-sufficient in electrical energy and mitigate the impacts of production (Guares et al., 2021).

This complex context, with a lot of technological evolution, requires producers to have new management skills related to decisions about the choice and viability of investments in the production process and thus keep up with changes in the sector. Based on this reality, rural producers have difficulty identifying which would be the best investment alternatives. Given the above, this study seeks to answer the following question: Which investment alternatives for DC should be chosen, and which are economically viable?

Given this scenario, the objective of this study is to build a constructivist multi-criteria model to evaluate different investment alternatives for DC, focusing on choosing the alternative with the best performance. As well as, developing a framework to adequately evaluate the economic-financial viability of the investment alternative with the best performance identified by the multi-criteria model.

2 Theoretical basis and research methodology

The research methodology and theoretical basis are structured into the following topics: (i) framework to choose dairy cattle (DC) investment project (IP); (ii) multicriteria model for alternatives in dairy cattle; and, (iii) economic-financial appraisal framework. The general framework for choosing investment projects in dairy cattle farming can be seen in Figure 1.

The general framework of this research seeks to propose a process for choosing and evaluating investment projects in DC farming. The first question that must be answered is whether the decision maker knows the best investment project alternatives. If the answer is positive, then it is recommended to analyze of the project's economic and financial viability.

If the answer is negative, it is necessary to ask the decision maker whether or not to increase knowledge about the objectives, criteria, and alternatives. If the answer is negative, it is recommended to use multi-criteria methodologies with a normative or descriptive approach and then prioritize the projects. If the answer is positive, it is recommended to question the decision maker if the context is complex, uncertain, and with multiple conflicting objectives, if the answer is positive, it is recommended to use the Multicriteria Decision Aid-Constructivist (MCDA-C) to the construction of the evaluation model.

With the model developed considering the uniqueness of the context and the prioritized investment projects, it is recommended to ask the decision maker whether would be able to say whether the project is viable from an economic-financial point of view. If the answer is positive, it is recommended to take the decision. However, if the answer is negative, it is recommended to carry out an economic-financial feasibility analysis and only then decide to implement the investment project. The next sections explore the theoretical and methodological basis of MCDA-C and the economic-financial viability analysis process.

2.1 Multicriteria model for alternatives in dairy cattle

The MCDA-C methodology, selected as an intervention instrument for this research, is based on the construction of knowledge in the decision-maker, taking into account their values and

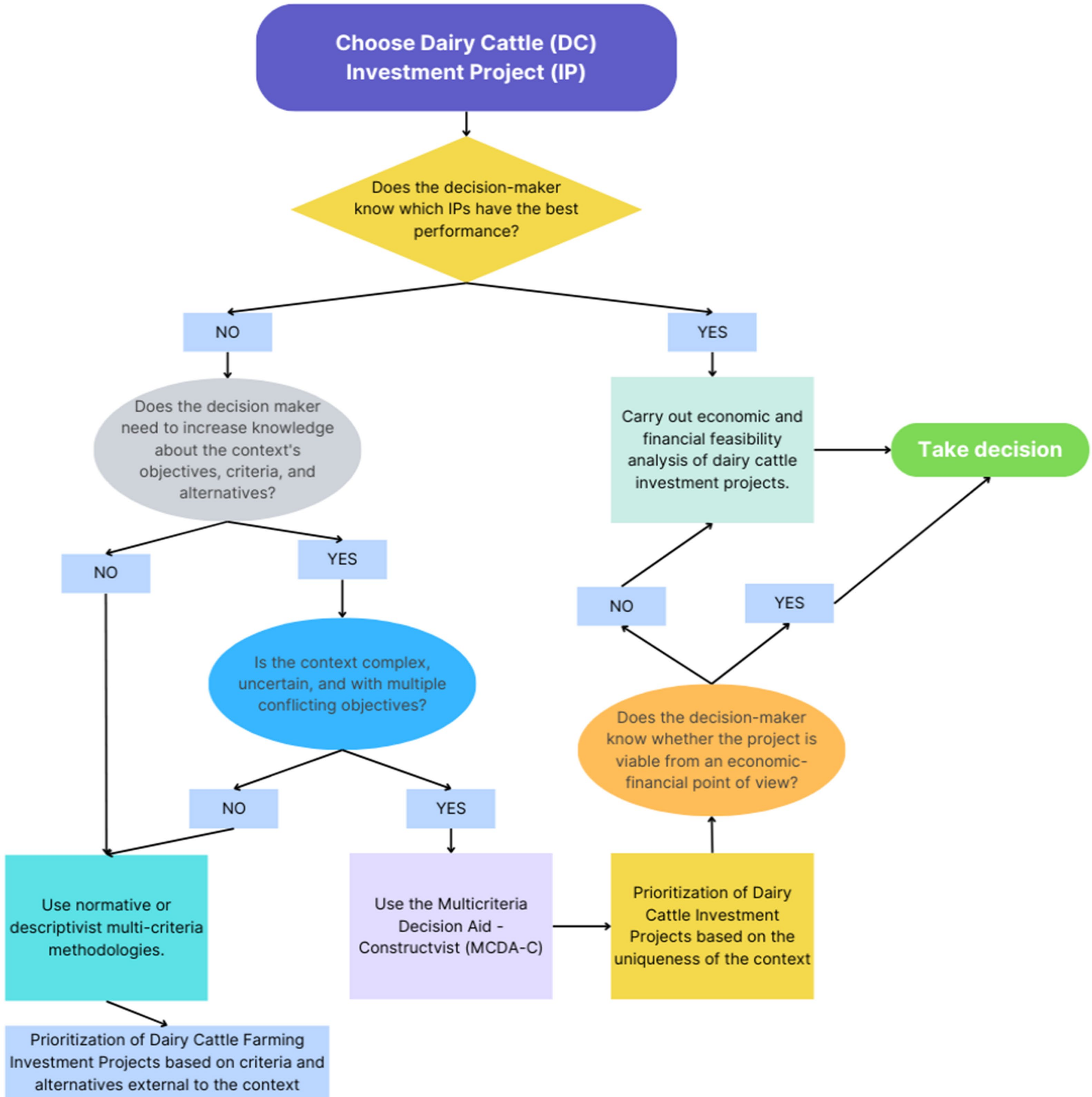

FIGURE 1
Framework for choosing dairy cattle (DC) investment project (IP). Source: Elaborated by the authors (2024).

preferences concerning the decision-making context (Ensslin et al., 2020a; Ensslin et al., 2020b). The focus of the MCDA-C methodology is on the development of unique models, regulated by the recognition of unique attributes (objectives and criteria) of each decision maker in their context (Roy, 1990). Knowledge is driven by the MCDA-C methodology through recursion and interaction between the decision-maker and facilitator (Caldatto et al., 2021).

MCDA-C assists decision-makers in the management process, accepting that organizational contexts are complex, as they involve multiple objectives, conflicting objectives between the actors involved, and uncertainty (Bana e Costa, 1993; Ensslin et al., 2010; Schlickmann and Bortoluzzi, 2023; Ensslin et al., 2014). Therefore, the use of MCDA-C is justified, considering the limits of objectivity (Roy, 1993), the complex, conflicting, and uncertain environment of dairy activity, and the need to develop a multi-criteria model to support the selection of investment projects for the rural property subject of the research.

The MCDA-C methodology is divided into three phases (Ensslin et al., 2000; Ensslin et al., 2001): (i) structuring phase; (ii) evaluation phase; and (iii) recommendations phase, as shown in Figure 2.

The structuring phase is concerned with identifying and organizing the relevant, necessary, and sufficient aspects in the decision-making context, taking into account the values and preferences of the decision-maker (Martins et al., 2023). This phase is divided into four stages: (i) soft approach to structuring; (ii) family of points of view; (iii) construction of descriptors; and (iv) independence analysis.

The soft approach stage for structuring consists of understanding the decision-making context in which the problem is inserted. The stage begins with the contextualization of the context, and then the

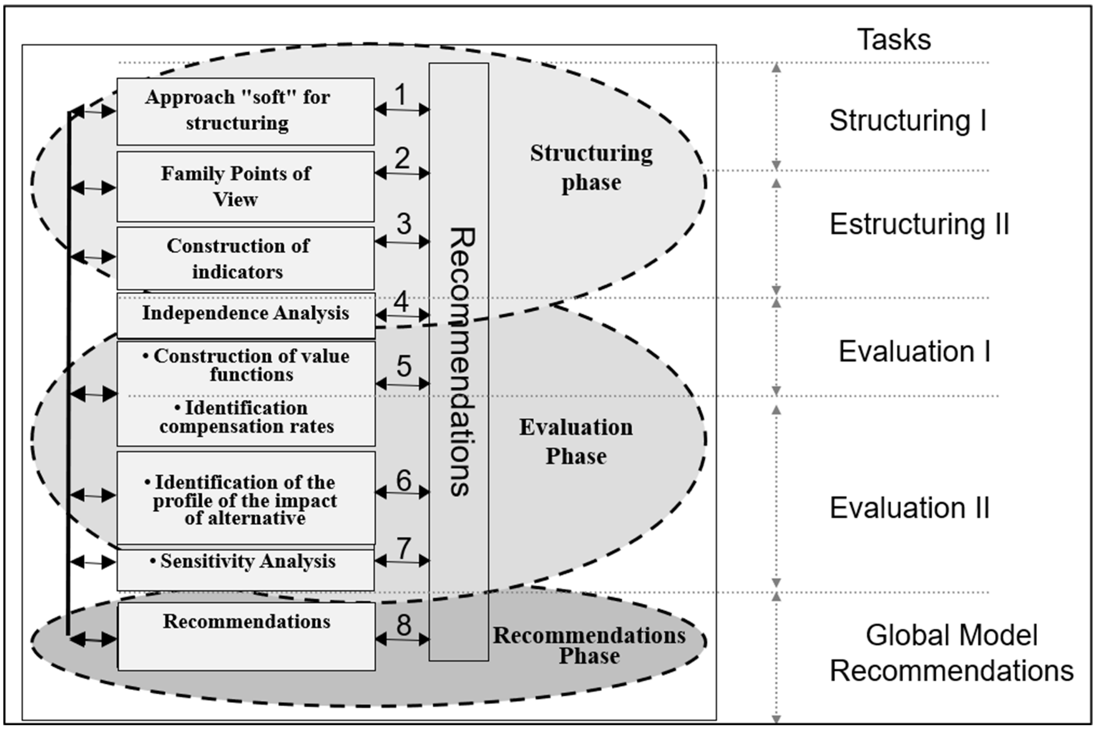

FIGURE 2
Flow of activities to be developed in the MCDA-C methodology. Source: Adapted from Ensslin et al. (2000, p. 81).

actors involved in the decision-making context are identified, namely: decision-makers, facilitators, interveners, and those who acted (Rodrigues et al., 2018; Ensslin et al., 2020a; Ensslin et al., 2020b; Bortoluzzi et al., 2010a). In the next step, the problem label is defined, indicating the purpose of the model; and finally, the summary, with the presentation of the problem, the justification, and the results that seek to be achieved (Bortoluzzi et al., 2017).

The stage of constructing the family of points of view first involves identifying the Primary Assessment Elements (PAEs), which are concerns expressed by decision-makers (Ensslin et al., 2001). To identify PAEs, several interviews are carried out, asking the decision-maker to discuss the context and reflect deeply on the concerns that influence the decision-making context (Ensslin et al., 2020a; Ensslin et al., 2020b).

Subsequently, the PAEs are transformed into action-guiding concepts, containing the expected performance, also called the present pole, and the situation to be avoided, i.e., the opposite psychological pole (Ensslin et al., 2017; Rodrigues et al., 2018). The concepts aim to generate a better understanding of concerns, delimiting boundaries between acceptable performance and intended performance (Ensslin et al., 2014).

In this process of expanding knowledge in the decision-maker, through the recognition of necessary, relevant, and sufficient attributes, the importance of carrying out subsequent interactions with the actors involved is highlighted, until qualitative saturation of the relevant and necessary aspects in the decision-making context is obtained (Capellin, 2022). Afterward, the action-oriented concepts are grouped into areas of concern called Fundamental Viewpoints (PVF; Eden, 1988). In this way, the concepts that explain the values and perceptions of the decision-maker are brought together in concerns related to the decision-making context within each evaluation dimension (Bana e Costa et al., 1999; Ensslin et al., 2000).

The next step is the construction of descriptors, which begins with creating cognitive maps (CPs) or maps of means-end relationships (Bana e Costa and Vansnick, 1994). MCs graphically represent the decision maker's concerns, to organize and develop knowledge, through the visualization of cause-and-effect relationships of concepts. It is noteworthy that new concepts may emerge in the construction of MCs (Ensslin et al., 2010; Ensslin et al., 2020a; Ensslin et al., 2020b).

With the elaboration of MCs, it becomes possible to transition all knowledge generated to a hierarchical structure of value (Bana e Costa, 1992; Bana e Costa and Vansnick, 1994). Next, the descriptors are created, which are measurement scales defined together with the decision maker and that enable the evaluation of the context in each Elementary Point of View (PVE; Bana e Costa, 1992; Bortoluzzi et al., 2017). At this moment, the scales are ordinal and contain the definition of reference levels (Ensslin et al., 2001), called Good Level and Neutral Level. At the end of this phase, it is possible to demonstrate a model composed of qualitative performance metrics (Ensslin et al., 2020a).

The independence analysis seeks to guarantee the isolability of the evaluation criteria. The ordinal and cardinal preferential independence tests are performed with the context decision maker. The independence test is a prerequisite for transforming the qualitative model into a quantitative model (Ensslin et al., 2001; Roy and Vanderpooten, 1996).

The evaluation phase is divided into three stages: (i) construction of value functions and compensation rates; (ii) identification of the impact profile of the alternatives; and (iii) sensitivity analysis.

The evaluation phase transforms the qualitative model into a quantitative model, allowing you to visualize the impact of actions at a tactical and strategic level. The transformation of the qualitative model into a quantitative one occurs by transforming the ordinal scale into a cardinal one and also by identifying the compensation rates (Ensslin et al., 2010).

To operationalize scale transformation and compensation rate activities, the software Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) (Bana e Costa, 1992; Bana e Costa and Vansnick, 1994) is used. The construction of the cardinal scale makes it possible to establish the value function that represents the decision maker's preferences around the points of view (criteria). The decision maker's options are entered into the MACBETH software through the qualitative judgment of the passage from one level to another on the ordinal scale. The judgment possibilities are: null, weak, very weak, moderate, strong, very strong, and extreme. With this judgment, the MACBETH software, through linear programming, develops a cardinal scale (Ensslin et al., 2010).

Compensation rates are also obtained with the support of MACBETH software. To carry out this activity, the set of criteria on which the decision maker will make the judgment is inserted into the software. The decision maker will judge the transition between one potential alternative and another. The possible judgments for the decision maker are: null, very weak, weak, moderate, strong, very strong, and extreme. With the judgments entered, the software, using linear programming, establishes the compensation rates (Ensslin et al., 2020a; Ensslin et al., 2020b; Dranka et al., 2020; Bana e Costa et al., 1999; Ensslin et al., 2010; Rodrigues et al., 2018; Ensslin et al., 2000).

With these two activities carried out (transformation of the ordinal scale into cardinal and identification of compensation rates) it is possible to evaluate performance at the tactical and strategic levels of the hierarchical value structure (Bortoluzzi et al., 2010b).

The second stage of the evaluation phase is to identify the impact profile of the alternatives, i.e., carry out measurements on the established criteria and verify their performance on local criteria (operational) and also performance at the tactical and strategic level (global performance). At this stage, it is possible to measure the global performance of the alternatives and thus establish those that obtain the best performance (Caldatto et al., 2021; Martins et al., 2023; Schlickmann and Bortoluzzi, 2023).

The third step of the evaluation phase is sensitivity analysis. Sensitivity analysis seeks to test the robustness of the model by verifying the impact on the global performance of small variations in compensation rates. If small changes in compensation rates do not influence the ranking order of alternatives, it can be considered that the model is robust for decision-making (Ensslin et al., 2020a; Ensslin et al., 2020b).

The last phase of the MCDA-C methodology is recommendations. This phase allows the decision maker to evaluate the alternatives included in the model and thus make choice decisions. The recommendations phase involves using the evaluation model, as it allows the decision-maker to verify the impact of alternatives on local descriptors and their impact at the tactical and strategic levels (Ensslin et al., 2020a; Ensslin et al., 2020b).

Finally, it is worth noting that detailed information about the MCDA-C methodology can be obtained in the following scientific research: (Caldatto et al., 2021; Martins et al., 2023; Schlickmann and Bortoluzzi, 2023; Ensslin et al., 2014; Ensslin et al., 2010; Ensslin et al., 2020a; Ensslin et al., 2020b; Longaray et al., 2015; Bortoluzzi et al., 2010b).

2.2 Economic-financial appraisal framework

To carry out any investment, it is necessary to study the current scenario of the enterprise and elaborate on investment alternatives (IA). For this, it is essential to know the indicators to structure a model that provides results to support decision-making.

After elaborating on the model supported by the MCDA-C methodology, it is possible to identify the best IA. In sequence, the investment evaluation was carried out to verify its economic viability.

In general, the evaluation of an IA's economic viability starts with data collection, taking into account the initial estimate of the investment (CF_0). Afterward, estimating the maintenance and operations costs (M&OC) and the expected revenues (R) is necessary. Finally, the degree of expected return and the level of risks associated with IA are evaluated (Souza and Clemente, 2012; de Lima et al., 2015; de Lima et al., 2016; Bernardi et al., 2017; Lizot et al., 2017; Dranka et al., 2020; Piovesan et al., 2021; Nespolo et al., 2022).

In this phase, the deterministic approach is applied via EMIM and/or the stochastic approach by MCS or ROA, both supported by the $AVEPI® web application (de Lima et al., 2017; de Lima et al., 2024; Dranka et al., 2025), following the phases presented in the flowchart shown in Figure 1 (Dranka et al., 2020; Guares et al., 2021; Petri, 2021; Piovesan et al., 2021; Nespolo et al., 2022; Vilani et al., 2024; Dranka et al., 2025).

ROA is used to analyze the best alternative's economic viability if there are managerial flexibilities (Copeland and Antikarov, 2002; Dranka et al., 2020; Vilani et al., 2024). After applying ROA, a conclusive report is developed.

On the other hand, if there is no management flexibility, the EMIM is used, and the sensitivity indexes are verified. If it is low, it is developed the conclusive report; however, if the sensitivity is high, the MCS is applied and a conclusive a report developed (de Lima et al., 2015; de Lima et al., 2017; Guares et al., 2021; Petri, 2021; Pacassa et al., 2022; de Lima et al., 2024; Dranka et al., 2025).

After carrying out the phases, there will be a position on the economic viability of AI. From that point, the decision maker makes the option to invest, not to invest, to postpone or anticipate the investment. If the option for investment is made during the execution of the IA, the decision maker must assess whether the results are what was projected. If this does not occur, actions must be implemented to correct deviations (Dranka et al., 2020; Guares et al., 2021; Petri, 2021; Piovesan et al., 2021; Nespolo et al., 2022; Vilani et al., 2024; Figure 3).

3 Results and discussion

In this section, the results of the case study carried out on a rural property located in Brazil will be discussed, for which a constructivist model was built to assist in the choice of investment alternatives for dairy cattle farming, and subsequently the assessment of viability economic-financial.

3.1 Multi-criteria decision aid—constructivist

In this section, we develop a multicriteria model for choosing Investment Alternatives (IA) on dairy cattle in a rural property. It is a case study, characterized by nature as applied, and of a descriptive character, with a qualitative and quantitative approach. The intervention instrument called Methodology Multicriteria Decision

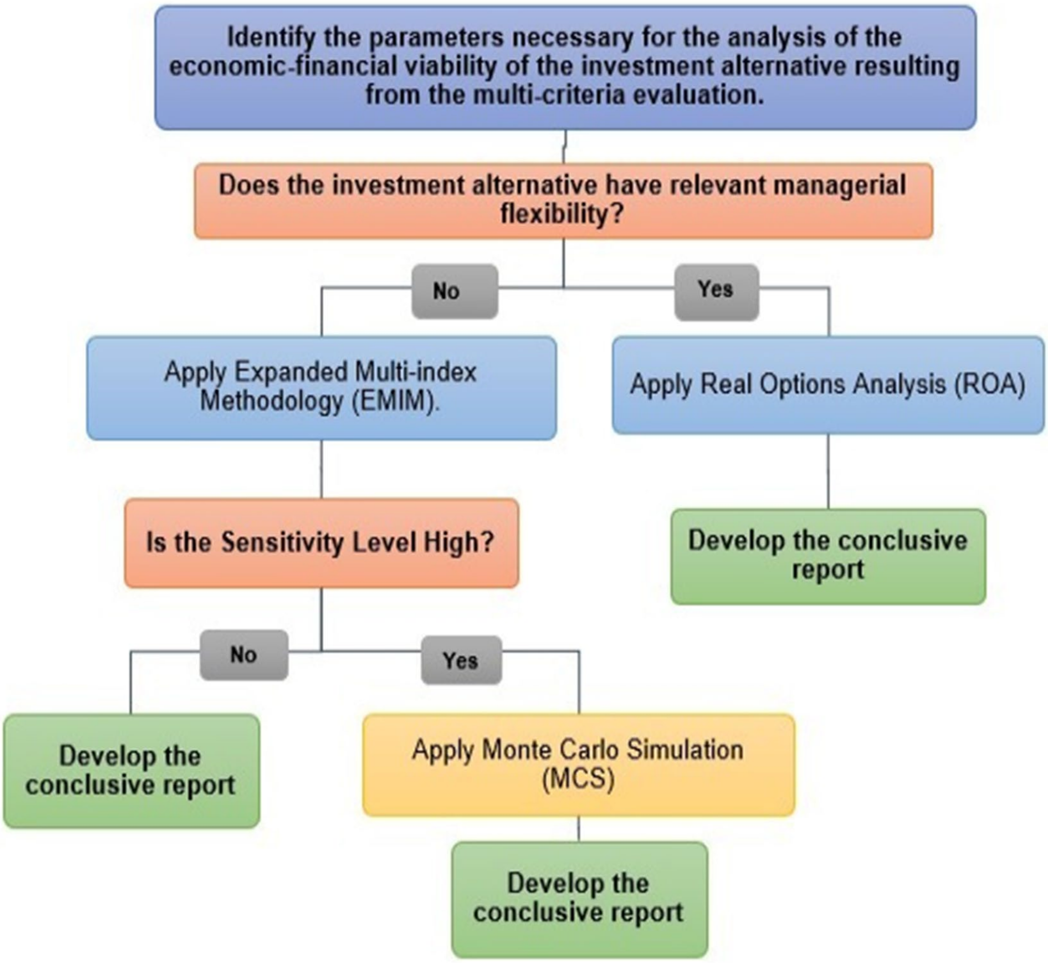

FIGURE 3
Framework for choosing the evaluation approach of the investment alternative. Source: Elaborated by the authors (2024).

Aid-Constructivist (MCDA-C) was used to develop the IA choice model for dairy cattle.

Following the methodological process presented in section 2.1, the model structuring phase is presented next, starting with the description of the soft approach to structuring.

The model was developed for a rural property located in the municipality of São Lourenço do Oeste—State of Santa Catarina—Brazil. The actors involved in the management and decision-making process of the rural property have the rural owner as the decision-maker, and the model was built through their perception. The parties involved are the other residents of the property, the wife, and the parents. The facilitator is one of the authors of this work, who sought to follow the methodology and integrate all the activities developed. As acted, the cooperative of which the owner is a member, the suppliers, banks, and the dairy were considered.

A label was also identified to present the problem (decision-making context): choosing dairy cattle investment projects on a rural property.

The rural property already has investment in dairy cattle farming, but there are countless possibilities for investment alternatives that can be implemented. However, there is a budget constraint on investment capacity as the owner does not have the financial resources to implement all possibilities. In this way, the model will make it possible to rank investment alternatives that meet the objectives of the rural decision-maker.

After the soft approach to structuring, the viewpoint family stage begins. At this stage, the Primary Assessment Elements (epas) were identified through interviews, in which the decision-maker can express their main objectives and concerns concerning the decision-making context of the property, with the dairy farming activity. Table 1 presents the epas identified in the interviews.

After identifying the epas, the rural producer sought to transform each EPA into an action-oriented concept, as a way of expanding the understanding of the decision-maker's objectives in the context (Table 2).

After completing the action-oriented concepts, the interview with the rural owner sought to construct the family of fundamental points of view, which, according to the decision-maker's perception, represent his objectives and what he considers most relevant in the development of the dairy activity. Figure 4 illustrates the family of views constructed.

Figure 4 shows that the four Fundamental Points of View (PVF) for the rural owner are: (i) profitability; (ii) sustainability; (iii) quality; and (iv) productivity. It is noted that, in addition to profits and production, the

TABLE 1 Primary assessment elements (EPAs) identified.

N°	Primary assessment elements (EPAs)	N°	Primary assessment elements (EPAs)
1	Improvement in working conditions	12	Purchase of food and inputs
2	Increased profitability	13	Investment costs
3	Increase production	14	Animal genetics
4	Limitation of land area	15	Milking cleaning
5	Productive herd	16	Family succession
6	Spending on medicines	17	Modernize milking system
7	Financial feedback	18	Sustainability
8	Lack of water	19	Manage the property
9	Production costs	20	Electricity cost
10	Milk quality	21	Environmental impact
11	Animal management	22	Milk price

Source: Elaborated by authors (2024).

owner is concerned with the quality and sustainability of the property, i.e., making profits with excellence and in the long term.

After completing the construction of the family of points of view, together with the decision maker, we sought to group the concepts constructed in the points of view to verify whether the family of points of view constructed was sufficient, and also whether all points of view were necessary identified view. Figure 5 illustrates the concepts are grouped in the pvfs, with the numbers below the PVF referring to the concepts previously elaborated.

The identification of PVF refers to the decision-maker's most relevant concerns, i.e., the strategic points. It can be seen in Figure 5 that all fundamental points of view present a homogeneous number of concepts, i.e., after testing adherence with the rural decision-maker, it was concluded that the pvfs were necessary and sufficient to represent the strategic objectives for the choice of investment projects for dairy cattle farming on rural properties.

The next step involves building the descriptors. In this stage, 4 cognitive maps were constructed to expand the decision-maker's knowledge of the context and to identify the Elementary Points of View (pves). After the construction of the Cognitive Maps, the transition was made to the rest of the hierarchical value structure (value tree).

After completing the hierarchical value structure, the ordinal descriptors were constructed. Additionally, Good and Neutral reference levels were established. Descriptors that perform at or above the Good level are considered excellent. Descriptors that performed between the Neutral and Good levels are considered competitive performance, and descriptors with performance equal to or less than neutral are considered compromising performance. Additionally, tests were carried out to guarantee the independence of the evaluation criteria. Figure 6 illustrates the model with the evaluation for alternative 3 of the investment projects in dairy cattle farming.

The next phase of the model is evaluation. This phase begins with the construction of the value functions and subsequently the transformation of the ordinal scale, built in the model structuring

TABLE 2 Outline of the concepts elaborated from the EPAs.

N°	EPAS	N°	Action-oriented concepts
1	Improvement in working conditions	1	Choosing projects to increase property profitability… failing to promote property growth
		2	Deleted.
		3	Prioritize projects that speed up milking with quality and efficiency. Waste time with manual work.
2	Increased profitability	4	Choose projects that increase revenue from the property's dairy activity. Continue with the same production system.
		5	Deleted.
		6	Deleted.
17	Modernize milking system	7	Choose projects that increase milked milk productivity. Continue with the same herd.
		8	Select projects that reduce the number of people in milking. Suffer from the consequences of forced and manual labor.
5	Productive squad	9	Choosing projects that make the most of the cows' productive capacity. Wasting the amount of milk produced.
		10	Deleted.
4	Limitation of land area	11	Select projects that use the entire productive capacity of the land. Avoid waste with unproductive areas.
		12	Deleted.
		13	Choosing projects that increase the volume of milk production. Losing productivity due to lack of daily control.
		14	Deleted.

Source: Research data (2024).

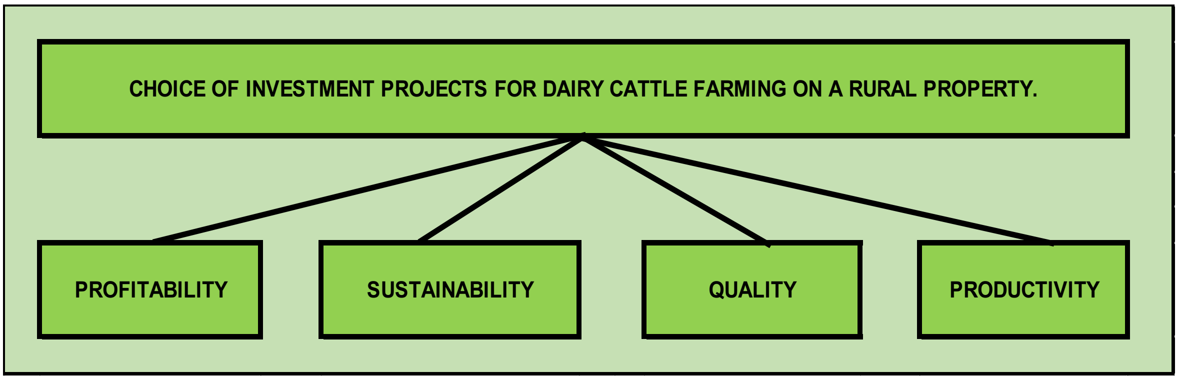

FIGURE 4
Family of fundamental points of view (FPVF) for evaluating investment projects in dairy cattle farming. Source: Research data (2024).

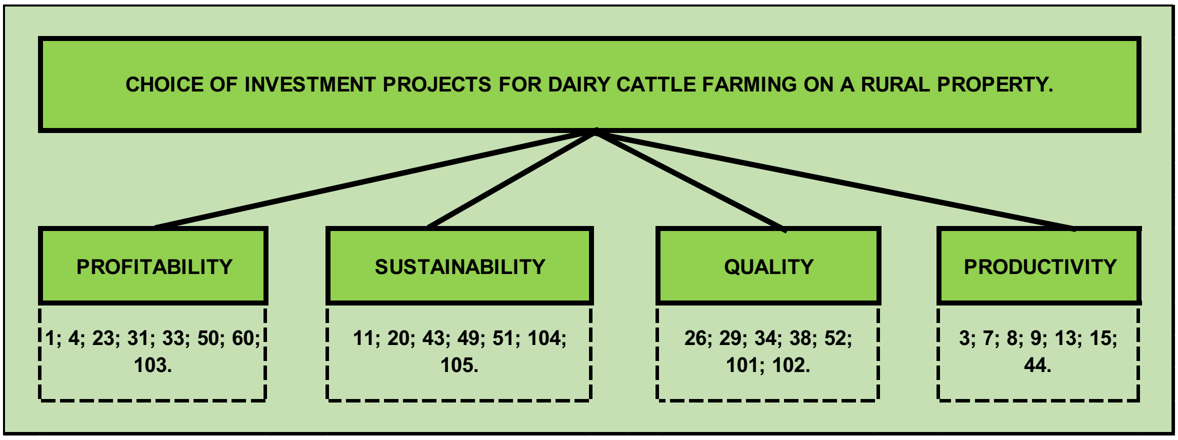

FIGURE 5
PVF adhesion test. Source: Research data (2024).

phase, into a cardinal scale. This transformation is carried out with the support of the Macbeth software and with the decision maker's judgment in identifying the difference in attractiveness between the descriptor levels. In this transformation, the Good and Neutral reference levels are equivalent to 100 and 0 points, respectively.

Based on the decision maker's responses, referring to the difference in attractiveness of all performance levels, a semantic matrix (verbal descriptions) is formed. Macbeth organizes all semantic judgments through linear equations, and with the help of a linear programming model, value functions are generated that satisfy all value judgments provided by the decision maker.

To make it possible to compare different impact profiles at the most strategic levels of the model, it is necessary to identify the compensation rates for the criteria (Ensslin et al., 2001; Ensslin et al., 2010). Thus, after completing the transformation of ordinal scales into cardinal scales, and the legitimization of these scales by the decision maker, the construction of compensation rates begins, which develops knowledge regarding the contribution of each criterion to the global model.

The first step to identify substitution rates is to rank the descriptors using the Roberts matrix (1979), which consists of asking the decision maker to give preference between the descriptors. After this step, the Macbeth software is used to generate compensation rates through potential alternatives.

The value functions and compensation rates make it possible to carry out a global performance assessment of each investment alternative (status quo) constructed with the decision maker (Table 3).

The identification of the status quo of each PVE in the model results from the sum of the multiplications of the compensation rate by the cardinal scale of the descriptors, according to Equation 1:

$$V(a) = \sum_{j=1}^{n} k_j * v_j\left[g_j(a)\right] \tag{1}$$

Where:

$V(a)$ corresponds to the global value of the alternative a.

$g_j(.)$ indicates the value of the descriptor of the PV_j.

$g_j(a)$ corresponds to the impact of alternative a on the value of the descriptor of the g_j.

$v_j[g_j(a)]$ is the partial value of the alternative a in PV_j.

k_j represents the value of the compensation rate of the PV_j.

Using Equation 1, it was possible to identify the performance of the global status quo and thus have the performance of each Dairy

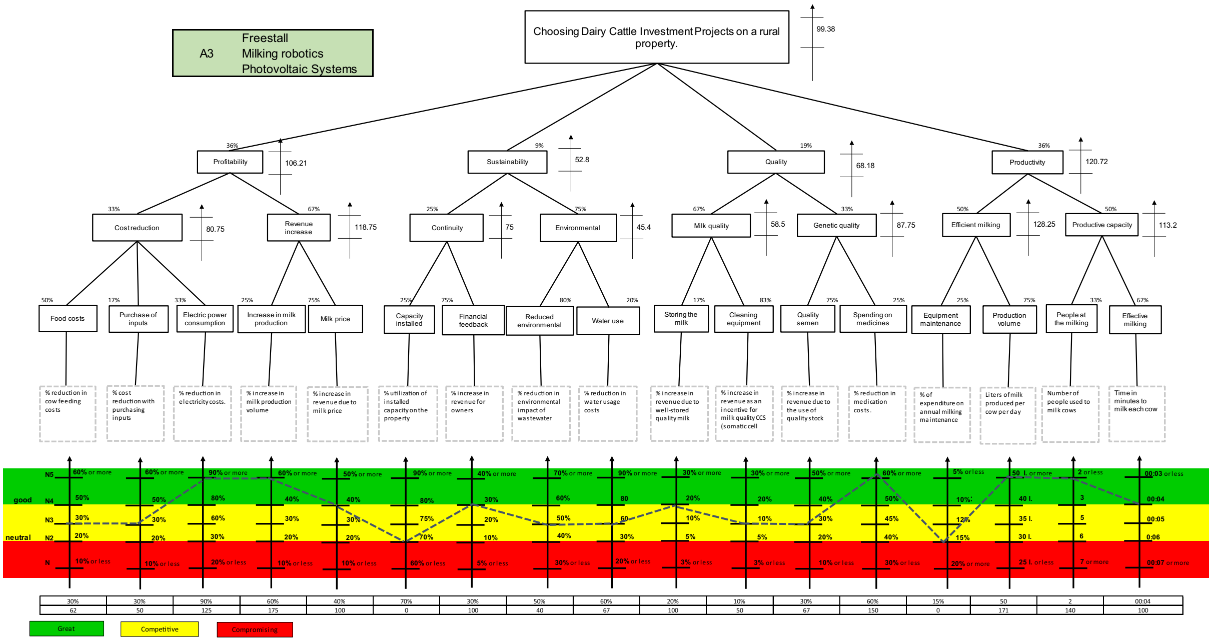

FIGURE 6
Assessment model for alternative 3. Source: Research data (2024).

TABLE 3 Alternativas de alternativas de investimentos.

A1	A2	A3	A4
Compost Barn	*Compost Barn*	*Free Stall*	*Free Stall*
Mechanized milking	Milking robotics	Milking robotics	Mechanized milking
Photovoltaic Systems	Biodigester	Photovoltaic Systems	Biodigester

Source: Elaborated by authors (2024).

Cattle Investment alternative, at each organizational level (strategic, tactical, and operational), reaching the global performance of each AIBL, as illustrated in Figure 7.

As shown in Figure 7, the AIBL that had the best performance was A3, which is composed of Free Stall, Milking robotics, and Photovoltaic Systems. It appears that its overall performance was 99.38, considered a good level, i.e., close to the level of excellence.

It is observed that because the model is compensatory, investment alternative A3 gains in productivity profitability, losing in sustainability, concerning investment alternative A2, which has better performance in sustainability but loses in profitability and productivity.

At the end of building the model, it was possible to present to the decision-maker the results of the BL investment alternatives that had the best performance, following its objectives. Additionally, a sensitivity analysis was carried out which demonstrated the robustness of the model, that is, the sensitivity analysis supported the understanding that small variations in compensation rates did not impact the inversion of alternatives. Figure 8 illustrates the ranking of alternatives.

To conclude this phase, an economic viability analysis of the investment alternative that had the best position in the ranking that the MCDA-C allowed to be carried out will be presented.

3.2 Evaluation of investment alternatives in dairy cattle

In dairy cattle, continuous changes require managers to seek technologies to improve sustainability. For this, it is necessary to identify and adequately evaluate investment opportunities. Thus, we develop an economic-financial evaluation of the investment alternative selected by the MCDA-C.

Upon completing the construction of the constructivist multi-criteria model (MCDA-C), it was possible to identify the investment alternative (AI) that performed best for the rural property, following the objectives and values of the rural owner and his family. As presented in the previous sections, the alternative that achieved the best performance was the A3, which is composed of Free Stall, milking robotization, and photovoltaic systems.

Following the objectives of this study, an analysis of the economic and financial viability of implementing this alternative on rural properties will be presented. To carry out this analysis, initial budget and maintenance surveys were carried out over time.

The property under study, already qualified in the previous section, is interested in investing in the continuity, expansion, and modernization of the dairy activity. To this end, surveys of the current situation were carried out. However, for economic viability, only what this alternative will add concerning current revenues and expenses will be considered, i.e., focus on the difference as recommended by the area of Economic Engineering (de Lima et al., 2015).

The initial investment (CF_0) of the selected alternative takes into account the equipment necessary to implement them on the property. Table 4 presents the detailed budget for this investment.

The initial investment (CF_0) includes the acquisition of 20 sows to add to those existing on the property, the construction of a shed with

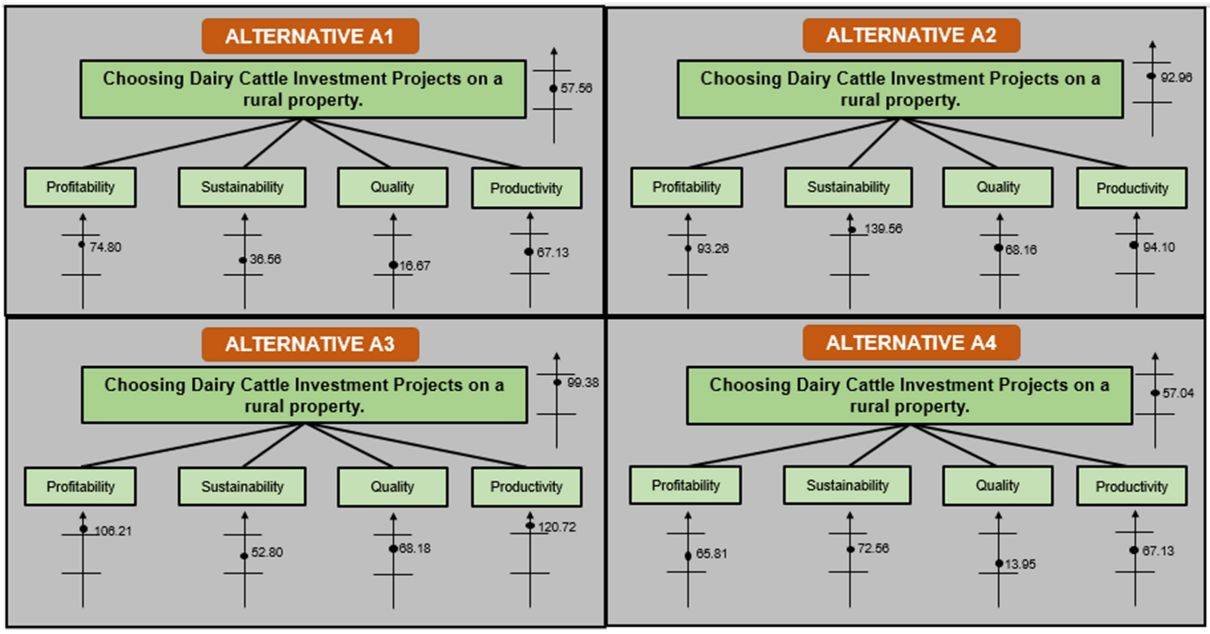

FIGURE 7
Assessment model for alternative 3. Source: Research data (2024).

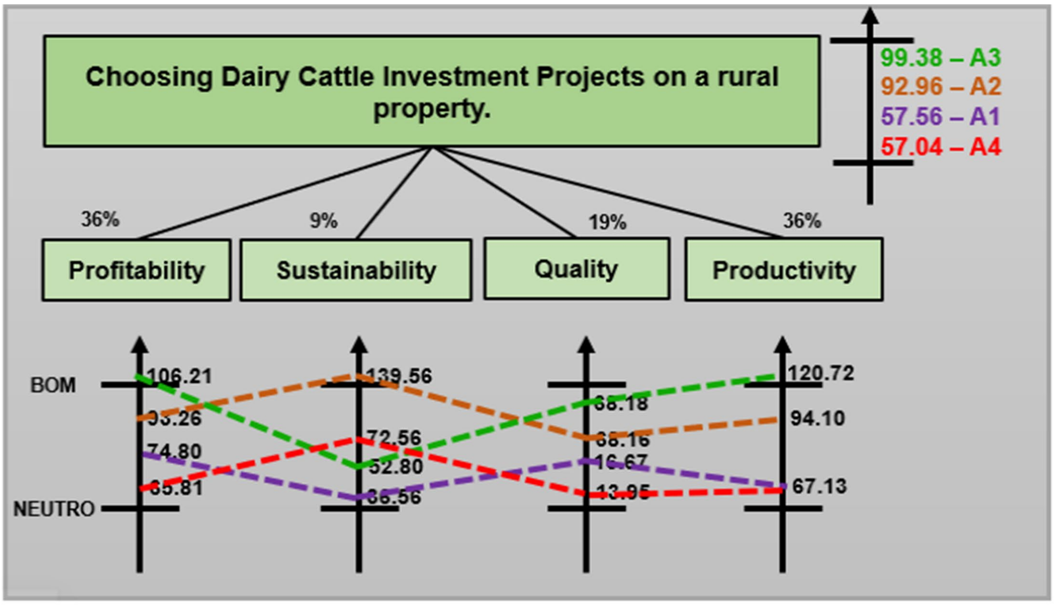

FIGURE 8
Overall performance of the 4 alternative investment projects in dairy cattle farming. Source: Research data (2024).

all the necessary equipment to enable dairy production, a milking robot, and a photovoltaic system, totaling R$ 1,760,000.00.

Next, the operation and maintenance costs of this investment were budgeted (average annual values). The estimated values are detailed in Table 5.

It is worth mentioning that the cost values for dairy activities are only the additional values that the property will have with the implementation of this alternative. The cost of maintaining the robot was budgeted with the manufacturer, as well as the photovoltaic system with the specialized company.

The expected revenues from this investment were calculated by selling fresh milk. The quantity used to calculate the revenue is only the increase expected with the purchase of more sows and the robotization of milking. The expected data are presented in Table 6.

According to an interview with the owner, measuring the average milk produced in the last year and calculating the difference in

TABLE 4 Data on budgeted initial investment (CF_0).

Item	Quantity	Unit value (R$)	Total value (R$)
Matrices	20	9,000	180,000
Free Stall Shed	1	380,000	380,000
Dividers	60	130	7,800
Drinking fountains	2	6,600	13,200
Fans	6	4,500	27,000
Sprinkler	1	30,000	30,000
Bed	1	15,000	15,000
Scraper	1	29,000	29,000
Robot	1	1,000,000	1,000,000
Photovoltaic System	1	78,000	78,000
TOTAL			1,760,000

Source: Elaborated by the authors (2024).

TABLE 5 Data on estimated operation and maintenance costs.

Item	Quantity	Unit value (R$)	Total value (R$)
Dairy activity costs	1	970,000	970,000
Robot maintenance costs	1	66,000	66,000
Preventive maintenance panels	1	500	500
Total			1,036,500

Source: Elaborated by the authors (2024).

TABLE 6 Data on expected revenues.

Item	Quantity	Unit value (R$)	Total value (R$)
Raw milk	504,000	2.90	1,461,600
Total			1,461,600

Source: Elaborated by the authors (2024).

production with the investment was possible. The calculated price was based on the CEPEA index of the average market price in Santa Catarina/Brazil. The expected annual value is R$ 1,461,600.00. From these data, it was possible to project the Cash Flow (CF) necessary for the economic viability (EV) analysis. The annual value of the CF was estimated at R$ 425,100.00.

Following the flowchart presented in the methodology, the next phase consisted of the EV analysis of the IA. After identifying that IA does not have managerial flexibility, the Expanded Multi-Index Methodology (EMIM) was applied, supported by the $AVEPI® web application.

The application was filled out with the following information about IA: (i) Minimum Attractive Rate (MAR) equal to 10% per year obtained based on the market rate (Souza and Clemente, 2012); (ii) Planning horizon (N) equal to 10 years; (iii) Initial investment (CF_0), which was detailed in Table 2; (iv) Annual Cash Flow (CF) equal to R$ 425,100.00, considered constant; and (v) Residual value (RV), which was considered null. Based on this data, the digital platform generated the EMIM indicators presented in Table 7. Based on this information, it was possible to classify the three dimensions of the EMIM: return, risk, and sensitivities, as shown in Figure 9.

In the return dimension, the IA indicated by MCDA-C requires a capital contribution (CF_o) in the order of R$ 1,760,000.00. This investment is expected to produce R$ 2,612,055.48 (PV). This implies a total net return (NPV) of R$ 852,055.48 in 10 years, equivalent to R$ 138,668.11 per year (NPVA). It is worth mentioning that this gain is always additional to that provided by the market, which is represented by the MAR equal to 10% per year. For this IA, for each monetary unit invested, there is an expected return of 1.4841. This is equivalent to a gain of 4.03% per year, in addition to the annual MAR of 10%. The return is best expressed by the ROIA/MAR index (Souza and Clemente, 2012), whose value obtained is 40.27%. This allows the investment to be classified as a medium-grade return (from 33.33 to 66.66%), according to the scale proposed by de Lima et al. (2015).

Regarding the risk dimension, IA expects a return on investment (Payback) in approximately 6 years. The Payback/N index is 60.00%, i.e., the IA has to be promising in at least 60.00% of the estimated life to present a financial return. On the other hand, the MAR/IRR index resulted in 49.09%, representing the ratio between the percentage offered by the market (MAR) and the maximum return expected by IA. This allows the investment to be categorized as medium risk (from 33.33 to 66.66%), according to the scale proposed by Lima et al. de Lima et al. (2015).

In the sensitivity analysis, for the IA under study, the MAR allows a maximum variation of 103.70% before making it economically unfeasible, with the limit value being equal to 20.37% (IRR). On the other hand, the initial investment (CF_0) supports an increase of up to 48.41%, with the limit value equal to R$ 2,612,055.48 (PV). Cash Flow (CF) allows a maximum reduction of 32.62%, with the limit value equal to R$ 286,431.89.

Based on these results (value below 33.33%, indicating high sensitivity), Monte Carlo Simulation (MCS) was applied, also supported by the computational tool $AVEPI®. It is worth mentioning that the objective of the MCS is to improve the risk perception of the implementation of the IA selected by MCDA-C. Thus, MCS will produce more robust results to better support the decision-making process.

The need to use MCS is more pronounced in investments that have high sensitivity. In the IA selected by MCDA-C, the index that requires the most attention is the Cash Flow (CF) variable. However, the MAR and the initial investment (CFo) were also considered as random variables. Table 8 presents the configuration adopted for the MCS.

In total, 100,000 pseudorandom simulations were generated with the support of the $AVEPI® digital tool, in which the planning horizon (N) was kept fixed at 10 years. The MAR, following a triangular probability distribution, with values varying from 5% minimum value to 14.25% maximum value, values based on the historical behavior of the Selic Rate in recent years (Brazil). The CF followed a triangular distribution, with minimum values equal to 80% of the most likely values and maximum values equal to 120% of the base values. CF0 followed a uniform probability distribution, with a variation of plus or minus 10%. The results found with the simulations are presented in Table 9.

TABLE 7 Economic analysis of the investment alternatives.

	Dimension	Indicator	Expected value
Extended methodology multi-index	Return	PV (R$)	2,612,055.48
		NPV (R$)	852,055.48
		NPVA (R$)	138,668.11
		BCI	1.4841
		ROIA (%)	4.03
		Index ROIA/ MRA (%)	40.27
	Risks	Payback (years)	6
		IRR (%)	20.37
		Index Payback/N (%)	60.00
		Index MRA/IRR (%)	49.09
Sensitivities	Elasticity limits (ELs)	Δ%MRA	103.70
		Δ%CF_0	48.41
		Δ%CF_j	32.62
		Δ%(CF_0 and CF_j)	19.49
		Δ%(MRA and CF_0)	33.00
		Δ%(MRA and CF_j)	24.81
		Δ%(CF_0 and CF_j and MRA)	16.41
	Limit-values (LVs)	MRA (%)	20.37
		CF_0 (R$)	2,612,055.48
		CFj (1 to 9) (R$)	286,431.89
		CF10 ($)	286,431.89

Source: Prepared by the authors with support from $AVEPI (2024).

MCS has improved the robustness of the investment decision risk level. Thus, the resulting probability distribution for the NPV in 100,000 random scenarios shows that the probability of financial failure [P (NPV < 0)] is 0.02%, i.e., there is a 99.98% chance of financial success, considering the variability incorporated in the simulations.

The value at risk ($VaR_{5\%}$) means that there is a 5% probability that the IA chosen by MCDA-C will generate a financial gain below R$ 480,355.92. In this context, an average gain of approximately R$ 413,137.45 (CVaR) is expected.

That said, it is possible to issue a conclusive opinion on the EV of the investment proposal. Given the average expected gain of R$ 894,364.46 (average NPV) and the probability of financial loss of 0.02% [P (VPL < 0)], it is recommended to implement the IA selected by MCDA-C, due to the expectation of a medium-grade return, associated with a low level of risk. Therefore, it is concluded that it is economically and financially viable to implement the alternative chosen by the multi-criteria model, which includes Free Stall, milking robotization, and photovoltaic systems.

In the economic-financial aspect, the implementation of alternative A3 proved to be economically viable, as the indicators presented are considered good, with a return above the invested capital. Considering a 10-year horizon, and maintaining the projected cash flow, the investment has a payback period of 6 years. With MCS, it was identified that the probability of IA success is 99.98%.

Other studies corroborate the application of EV analysis adopted to conduct this case study. Lopes et al. (2021), in the EV study of the implementation and installation of free stalls for dairy cattle, using MCS, found positive NPVs for all simulated scenarios.

The research by Pacassa et al. (2022) on the EV of the use of robotic milking, with the application of MCS, found zero probability of the investment presenting financial losses, within the analyzed variability. Furthermore, the values for the extreme risk indicators: Value at Risk ($VaR_{5\%}$) and VaR Conditional ($CVaR_{5\%}$) were positive, demonstrating the financial security of the investment.

Nespolo et al. (2022), in the EV study of the implementation of a photovoltaic system in dairy cattle, identified promising results with the application of EMIM and MCS. All simulated random scenarios were positive. The risk dimension indicators showed that the project presents a low level, presenting a return on invested capital in approximately 9 years. The analysis of the $VaR_{5\%}$ and $CVaR_{5\%}$ indices showed that even the worst scenarios were considered to present significant returns.

Thus, these studies present isolated analyses, that is, they evaluate the EV of implementing just one previously identified investment project on a rural property. On the other hand, the purpose of this paper was to jointly analyze an alternative to increase the profitability of the property under study. With interaction between producer and researcher, it was possible to collect the data necessary for the evaluation of the EV of implementing joint project alternatives and conclude that the proposal is economically viable.

Therefore, the decision to invest in new technologies needs to be evaluated using a multi-criteria method, followed by an adequate EV analysis of the added value and risks associated with the investment.

4 Conclusion

This study proposed building a model for choosing and evaluating investment alternatives for dairy cattle farming. To meet the initial objectives, a systematic literature review was carried out, in which works and research relevant to the subject were obtained. In this way, gaps can be observed in the literature, referring to the constructivist paradigm, adopted by the research. Thus, opportunities were identified, such as the construction of a model that helps in the choice and evaluation of investment alternatives linked to dairy production.

Regarding the analysis of economic viability, in the works found in the literature, only individual projects are evaluated, or comparisons between one investment or another. With this, this research developed a study to identify investment alternatives with the participation of rural producers, seeking to rank the alternative with the best performance supported by a constructivist multi-criteria model, in the objectives and criteria defined by the decision maker, which in

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Dimension	Index	Low (< 33.33%)	Medium (from 33.33% to 66.66%)	High (> 66.66%)
Return	ROIA/MRA		40.27	
Risk	Payback/N		60.00	
	MRA/IRR		49.09	
Dimension	**Index**	**High (< 33.33%)**	**Medium (from 33.33% to 66.66%)**	**Low (> 66.66%)**
Sensitivities	Δ%MRA			103.70
	$\Delta\%CF_0$		48.41	
	$\%CF_j$	32.62		

FIGURE 9
Overall performance of the 4 alternative investment projects in dairy cattle farming. Source: Research data (2024) supported by $AVEPI®.

TABLE 8 Configuration configured for the MCS.

Parameter	Minimum value	Most likely value	Maximum value
MAR (%)	5%	10%	14.25%
CF_0 (R$)	1,584,000.00	1,760,000.00	1,936,000.00
CF (R$)	340,080.00	–	510,120.00

Source: Elaborated by the authors (2024).

TABLE 9 Descriptive and inferential statistics obtained with the MCS.

Descriptive statistics	NPV
Quantity	100,000
Minimum	172,367.20
Maximum	1,815,326.23
Range (Max – Min)	1,642,959.03
Mean	894,364.46
Standard Deviation	251,699.32
Coefficient of Variation	28.14%
Median	879,933.34
P(NPV < 0)	0.02%
$VaR_{5\%}$	480,355.92
$CVaR_{5\%}$	413,137.45

Source: Prepared by the authors based on the MCS results generated by $AVEPI®.

addition to profits and production, is concerned with the quality and sustainability of the property, i.e., making profits with excellence and in the long term.

With this interaction, it was possible to respond to the problem of this research: which investment alternatives in dairy cattle farming should be chosen and which are economically viable. With the construction of the model, it was possible to identify the best alternative with 99.38 performance level points, i.e., close to the level of excellence, following the criteria of the MCDA-C model.

The greatest contribution of this research was the integration of MCDA-C (construction of the choice model) with the framework (adapted from recent research on the topic), to evaluate the best-ranked alternative. The limitations are the data, which were used only from one rural property, with the model being unique to the decisions and preferences of the rural producer and his family.

Due to limited time for research, it was not possible to monitor the implementation of this alternative. Therefore, it is suggested that future studies monitor and monitor this alternative on the property under study. For this, the EMIM elastic limit indices and limit values can be used. Furthermore, the use of the interaction of these research methods can be replicated in other rural properties, which aim to invest, but with security and reliability in the data, avoiding risks and improving profitability.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: case study. Requests to access these datasets should be directed to simonebeatrizwolfart@hotmail.com.

Author contributions

SW: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. DE: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JL: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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