Real Options in Sustainable Agriculture: an arrangement between the build-to-suit and the carbon market

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Abstract
This paper demonstrates the effectiveness of utilizing the real options approach in analyzing investments in "green cattle". The primary objectives include discussing real options theory and illustrating its application in modeling uncertainty and managerial flexibility in a collaborative relationship between a small farmer and a high-emission industry company aiming to reduce emissions through a build-to-suit contract of the land and trading carbon credits produced in the land. Additionally, the paper demonstrates the calculation of specific options, focusing on this contractual arrangement. The analysis explores two management options: expanding business activity and delaying investment. Considering the stochastic nature of future cattle and carbon credit market prices, the Monte Carlo simulations unveil a notable inherent risk, contrasting with conventional analyses that may imply profitability. The real options approach indicates a significant value when an option is exercised, with the level of uncertainty in the expanded model dropping 71%, demonstrating that the option holds substantial value. Sensitivity analysis for input option parameters further emphasizes the limitations of the traditional model to adequately address management's ability to adapt to economic shocks, risks, and uncertainties in investments involving build-to-suit, carbon credit, and green cattle.
keywords
Sustainable farming partnership, Carbon credits, Build-to-Suit, Real options model.

1. Introduction

Brazil is a global agricultural potency known for the strength of its agricultural sector, which plays a crucial role in the country's economy. In particular, the livestock sector is fundamental to food security and job creation and contributes significantly to the gross domestic product (Zilli *et al*., 2020). Responsible for the large-scale production of beef, pork, and poultry, the sector not only serves the domestic market but also has a substantial influence on exports, solidifying Brazil's position as one of the world's leading exporters of animal products (Casagranda *et al*., 2023).

However, small farmers face substantial challenges related to a single source of income (Souza Sant'Anna and Nelson, 2017). Moreover, the edaphoclimatic conditions contribute to the heterogeneity of agricultural experiences. In some regions, the fertility of the soil combined with favorable climatic conditions generates high agricultural returns, while in other regions, monoculture can create significant vulnerabilities (Jordão and Moretto, 2015).

In this context, the aim of this article is to propose a model for expanding the activity of a small farmer to sell "green cattle" through a partnership between the farmer and a company that needs to reduce its carbon emissions. This partnership is signed through a Build-to-Suit (BTS) real estate contract. Through this association, the company rents part of the land for afforestation or reforestation aimed at the carbon credit market, while the farmer gains the flexibility to trade "green cattle". We consider green cattle to be those whose gas emissions are fully offset. The pricing of the expansion option is done using the real options approach.

In the last years, consumers' willingness to pay for green products cannot be ignored (Rezai *et al*., 2013; Katt and Meixner, 2020). Consumer research recognizes that their perceptions of a product, attitude, knowledge about the product and its manufacturer, and various contextual factors play a dominant role in their decision-making process (Biswas, and Roy, 2015). However, the intention to pay the premium for green products has remained unexamined primarily in the context of emerging economies (Biswas and Roy, 2016).

Tsai *et al*. (2012) discuss the importance of considering carbon dioxide emission costs in the production of green products. Furthermore, the authors analyze the concept of carbon trading, where companies can buy and sell carbon credits to meet their emission reduction targets cost-effectively. Carbon markets operate based on a cap-and-trade system, where a maximum allowable quantity of emissions is set (the cap), and companies can trade allowances to comply with this limit. This system incentivizes companies to reduce emissions efficiently and provides flexibility in meeting regulatory requirements. The carbon market represents an active response to environmental challenges by aligning sustainable agricultural practices with economic gains (Perez et al., 2007; Milder et al., 2010).

On the one hand, the sale of carbon credits can generate a virtuous cycle of sustainability and profitability for small farmers (Mathews, 2008; Bansal et al., 2023), including the sale of green products. On the other hand, entering this market presents numerous challenges that can be particularly onerous for small producers. It requires significant investments in technology, training, and changes to traditional operations. Additionally, the complexity of the certification and verification procedures for sustainable practices can be a considerable barrier (Moura et al., 2000). Also, the lack of familiarity and access to information on how the carbon credit market works poses a further challenge. The complexity of the contracts, the variation in market rates, and dealing with intermediaries can be intimidating and represent significant barriers for those without the experience or resources to seek expert advice (Lee et al., 2018).

Faced with these challenges, producers could explore strategic partnerships with companies interested in reducing their carbon emissions. This cooperation could be established through the BTS model, commonly used in the real estate sector to provide customized solutions for tenants' specific needs, offering a custom-built environment for their activities. The BTS contrasts with traditional leasing models, where tenants usually adapt to existing spaces. In BTS, landlords can attract high-quality tenants and establish long-term partnerships. This model reflects the evolution of traditional leasing practices, offering flexible solutions to tenants (Abidoye et al., 2022).

To the best of our knowledge, the combination of the BTS with the carbon credit market is a novelty proposed in this paper. The design of the project would involve the rural producer renting out part of his land so that the rental company can plant trees for the carbon market. This model contributes to diversifying the small farmer's activities and provides the company with a reasonable solution for achieving its emission reduction targets. The company assumes responsibility for the costs involved in planting, maintaining the trees and certifying the area in exchange for receiving the carbon credits generated on the property. The producer receives the necessary guarantee from the company to take out a bank loan to buy the property, receives part of the revenue from the sale of carbon credits and acquires the option to sell the "green cattle".

The real options model is used to assess the opportunities and risks embedded in the proposed approach. Here, the irreversible cost is represented by the investment in property certification, an essential element to make sustainable marketing viable. The uncertainties inherent in the cattle price futures market and variations in carbon credit are incorporated into the model, reflecting the complexity of the environment. Managerial flexibility is highlighted by the possibility of earning additional income by selling "green cattle". This European-type option allows sequential decisions to be considered over time, enabling a more comprehensive and realistic analysis of the economic and strategic viability of this sustainable livestock production alternative.

This paper provides a holistic understanding of the economic opportunities arising from a producer-company partnership. Moreover, this approach offers a new perspective on sustainable investment for small farmers and fills a gap in the literature between sustainability and agricultural finance. To the best of our knowledge, the authors are not aware of any other papers that address a similar proposition.

The findings show the financial contribution of income from "green cattle" for small-scale ranchers. The results suggest that the joint implementation of BTS with carbon credits can promote sustainable practices and add significant value to the farm's total income. Our analysis shows that the partnership between small farmers and companies contributes to environmental preservation and generates economic benefits for farmers.

This article follows the structure outlined below. After this introduction, section 2 presents a literature review that provides an understanding of the functioning of the carbon market, the regulatory aspects involving the BTS model, and how these structures connect with the agricultural market in Brazil. This section also presents recent advances in real options within the context of the agricultural sector. Section 3 addresses the proposed methodology. First, the adaptation of the BTS model for rural producers is presented. Then, the real options model for calculating the expansion option is presented. Section 4 presents the case study and its main results. Section 5 discusses the results of the risk analysis. Section 6 discusses issues of using forest carbon offsets in public policy to improve farmers' environmental outcomes. The conclusion is presented in section 7.

2. **Literature Review**

2.2. Sustainable Agriculture

Agriculture plays a key role in developing economies, either because it employs a large portion of the population or because it accounts for a large part of their exports. In particular, Brazil is one of the world's main breadbaskets, and shocks to its agricultural sector have important implications for global commodity markets (Pellegrina, 2022).

Brazil has great production potential for quality meat, with pasture-based production (Ferraz and Felício, 2010), a favorable climate, suitable soil, cheap labor and water availability. Pasture-based animal production is recognized as advantageous in the pursuit of more sustainable agriculture (Chang et al., 2015) for their high potential for productivity improvement through smaller cost and low-impact practices. Livestock is a major driver of rural landscapes and economics, provides different ecosystem services (Dumont et al., 2019), and plays a key role in food security and bioeconomy by converting forages, crop residues, and agricultural by-products into high-value foods (Mottet et al., 2017). Animal production contributes to human nutrition and health, guarantees subsistence and poverty reduction, and gender equality (Adesogan et al., 2020).

On the other hand, livestock are a large contributor to the climate change problem (IPCC, 2007). Livestock farming contributes 18% of global anthropogenic greenhouse gas (GHG) emissions (Steinfeld et al., 2006). The main sources and types of greenhouse gases from livestock systems are carbon dioxide (CO2) from land use and its changes (feed production, deforestation), which accounts for 32% of livestock emissions; nitrous oxide (N2O) from manure and slurry management, which accounts for 31%; and methane (CH4) production from ruminants, which accounts for 25% of emissions.

High impacts in terms of greenhouse gas (GHG) emissions (Poore and Nemecek, 2018) and land use (Ridoutt et al., 2019) are attributed to this activity. Livestock systems need to adapt in the future by improving production technologies and husbandry methods (Agrawala and Fankhauser, 2008). It is likely that agriculture and livestock farming in particular will have to play a much greater role in reducing GHG emissions than they have so far.

In general, reducing carbon emissions does not depend on just one pathway. Instead, it requires the synergistic effect of several strategies aimed at reducing carbon emissions (Broadstock et al., 2021). According to Can (2021), the combination of policy assurance, the role of pilots, technological innovation, financial support and multi-objective collaboration could lead to a better realization of carbon neutrality.

2.3.Carbon Market

Reducing global emissions that impact climate change will be a constant task in the 21st century. Limiting the increase in global average surface temperature to approximately 2°C would imply cutting global emissions by at least 50-85% by 2050 (IPCC 2007; Meinshausen et al. 2009). The transition to a low-carbon economy will require the participation of all major emitters, including emerging economies. As such, policies to encourage low-carbon investment in these economies are an essential component of an effective global climate policy.

Currently, the approach to climate policy is based on carbon emissions trading. It is hoped that carbon markets, through the invisible hand, will stimulate the diverse and creative applications of new and existing technologies that are expected in this low-carbon transition. However, it is important not to ignore a number of cultural and institutional factors that can impede or enhance large-scale policy approaches (Hultman et al., 2012).

Emission reductions can be achieved, for example, through afforestation and reforestation (A/R) activities, which can be sold in the form of carbon certificates. Due to their high CO2 sequestration potential, forests are an important sector of the global carbon credit market (Bumpus and Liverman 2008; UNFCCC 1997). Forests absorb the equivalent of around 2G of CO2 per year (FAO 2018).

Carbon pools allow developed economies to achieve their emission reduction targets by purchasing carbon credits associated with projects in developing economies (UNFCCC 2007). Parallel to the the Kyoto Protocol’s Clean Development Mechanism (CDM), a Voluntary Carbon Pool Market (VCM) has emerged with private actors, in which carbon credits are sold in the form of Verified Emission Reductions (VER), with each VER corresponding to 1 t of CO2 equivalent (Bumpus and Liverman 2008).

The VCM was intended to solve the excessive bureaucracy and lack of sustainable development co-benefits of the CDM market. On the other hand, the VCM lacked transparency and double-counted target sets. For these reasons, voluntary carbon offset standards were created to standardize the quality of projects eligible for carbon offsets (Lovell 2010). One of the most important carbon offset labels, especially in the forestry and land use sector, is the Gold Standard. It was initiated in 2006 by the World Wide Fund for Nature (WWF) and offers various methodologies under which projects can be certified, including an "A/R Methodology for GHG Emissions Reduction and Sequestration" (The Gold Standard 2017).

When deciding on investments in certification, for example with the Gold Standard, project managers face uncertainty. In addition, strong carbon emission certifications can increase consumers' willingness to pay for carbon credits and the associated benefits (Liu et al. 2015; MacKerron et al. 2009). On the other hand, establishing and maintaining certification for a project usually entails high costs and risks, and there is little research available on the overall benefits of certification (Galik and Jackson 2009).

The decision whether or not to apply for certification is therefore influenced by many factors, including the time and effort needed to prepare and maintain certification, the certification fee, possible additional income or the change in consumer perception of the project. Some of these variables are difficult to quantify, which makes the decision about possible certification complex and difficult. This is particularly the case in forestry and agricultural systems, which are characterized by uncertainty and dynamically changing and interacting factors (Netter, 2022).

2.4. Build to Suit (BTS)

One hybrid in real estate practice is the lease for the construction of a property. It involves a construction contract and a lease agreement combined into a single document. When drafting and negotiating a BTS lease contract, professionals must focus on issues arising in both lease negotiations and the construction contract (Etter, 1997).

As in any construction project, the landlord and the tenant in a BTS lease agreement are focused on completing the work (1) on time, (2) within the allocated budget, and (3) properly, in accordance with construction plans and specifications and applicable building laws and regulations. The landlord receives rental payments after the work has been substantially completed. It is not uncommon for the tenant to be responsible for the project's design phase, while the landlord handles construction, especially in the case of large tenants (Bernhardt and Goodrich, 2016).

Accordingly, a "build-to-suit" lease agreement is any lease contract that refers to some construction to meet the tenant's needs. The contracting party's goal is not the acquisition of the property but solely the use of the constructed asset. In this real estate contract model, the investor acquires land and hires a development company to carry out the construction, at the request of another party interested in leasing, not purchasing the building (Figueiredo, 2010).

Companies from various sectors reduce their exposure of capital in owned properties, opting to lease custom-designed facilities to meet their operational needs (Gasparetto, 2009). In this operational model, the contracting party transfers to the contractor the burden of acquiring land and building a custom property that meets its needs. Thus, through BTS, the contracting party obtains a customized property and preserves capital to invest in its own activities (Omoju, 2020).

This construction can range from adding small tenant-finishing items to a general commercial office to the design and complete construction of a new building specially tailored to the tenant's commercial needs (Zanetti, 2011). Typically, smaller constructions in an existing building are addressed with the addition of a simple work letter to a standard lease agreement. Usually, these work letters become longer and more detailed as the level of construction increases. For a full project and construction lease agreement, the work letter can approach the complexity of a complete construction contract. In fact, the parties are conducting two related transactions. The tenant is hiring the landlord for the construction of a significant building and, simultaneously, is entering into a transaction to lease the newly constructed building, usually for a substantial period (Bernhardt and Goodrich, 2016).

Figure 1 illustrates the process for the BTS. According to Mere and Sivana (2020), the main advantage of BTS is that, with minimal resource utilization, the tenant receives a space truly tailored to their needs, which, being new, could be adapted with the latest technology and design applicable to the beneficiary's industry. On the landlord's side, there is a clear benefit related to the income derived from investments. By acquiring and developing the property, the investor obtains an asset that will generate fixed rents for a certain period, meaning from the outset, there is an assurance of a specific return on their investments in the BTS project. On the other hand, the authors emphasize that the BTS project may lead the beneficiary to pay a higher rent than other direct leasing alternatives and a much lower vacancy of the property. This type of contract is provided by the Brazilian Law nº 12.744/12.

Figure 1: The process for the BTS.
Source: Elaborated by the authors.

2.5.Real Options

The concept of ROA (real options analysis) originates from financial options markets (Borison, 2005; Mun, 2006b). Financial options in commodity markets are derivative securities whose value is derived from other financial securities known as the underlying asset. Essentially, an option grants the right, without the obligation, to buy (call option) or sell (put option) an underlying asset at a predetermined price until a specified future time. There are two primary exercise styles for options: European and American. European options can only be exercised on the expiration date, while American options can be exercised at any time before or on the expiration day (Chance and Brooks, 2009).

In contemporary business practices, capital budgeting decisions are increasingly being viewed as a series of options unfolding over time. Managers adjust their operational strategies as new information emerges, and uncertainties regarding market conditions and future cash flows gradually dissipate. For an investment to be viable, it must not only generate a positive NPV (net present value), but the expected returns from the immediate investment must also surpass the expected returns from delaying the investment (Dixit and Pindyck, 1995; Miller and Waller, 2003). According to ROA, the decision to invest in a new land use can be likened to an American-style call option (Tubetov et al., 2012). Similarly, the decision to abandon a specific land use or cease the production of a specific crop can be compared to a put option (Tauer, 2006).

In comparison to the NPV method, the fundamental principle of ROA lies in adjusting investment triggers, delineating critical revenue levels at which an investor deems it optimal to enter or exit an investment. This adjustment is made when the investment involves intertemporal opportunity costs (Musshoff, 2012; Seyoum and Chan, 2012). The influence of option values on investment thresholds can be significant (Schatzki, 2003; Song et al., 2011). For instance, Tozer (2009) observed that the rates of return necessary to initiate investment in precision agriculture equipment in Western Australia were 96 to 156% higher than the NPV breakeven point. The rationale behind this is that proceeding with an investment eliminates the investment option. The investor forfeits the opportunity to wait for additional information that could have influenced the investment decision (Tubetov et al., 2012).

ROA has found extensive applications in livestock and forestry, including optimal harvest and rotation (Gjolberg and Guttormsen, 2002; Insley, 2002; Plantinga, 1998; Saphores, 2001; Thorsen, 1999; Fernandes et al., 2017), processing capacity (Duku-Kaakyire and Nanang, 2004), and the valuation of forestry concessions (Rocha et al., 2006; Yap, 2004). In the agricultural domain, ROA has been utilized in scenarios such as organic farming (Irene and Konstadinos, 2009; Kuminoff and Wossink, 2010; Tanner Ehmke et al., 2004), the adoption of precision agriculture (Tanner Ehmke et al., 2004; Tozer, 2009), expansion of agricultural enterprises (Hinrichs et al., 2008; Odening et al., 2005; Tozer and Stokes, 2009), the adoption of genetically modified crops (Nadolnyak et al., 2011), and adaptation to climate change (Hertzler, 2007; Nelson et al., 2013; Sanderson et al., 2015).

While fewer examples exist, ROA has been applied to environmental land issues, including evaluations of the option to develop wilderness areas (Arrow and Fisher, 1974; Chambers et al., 1994; Conrad, 2000; Conrad and Kotani, 2005) and preserve biodiversity (Kassar and Lasserre, 2004). ROA has also been applied to analyze the observed slow response of wine grape farmers in exiting the industry amid persistent declining farm revenue (Seyoum and Chan, 2012). The authors found that considering large sunk capital expenditures and revenue uncertainty, the prices required to trigger industry exit decreased by as much as 32% compared to NPV breakeven revenues.

The uncertainty in forestry projects and management reactions to changes in assumptions are inadequately addressed from an options perspective. Thorsen's (1999) study is limited to the application of real options theory to determine the appropriate level of subsidy for an afforestation project in Denmark. The author compared the optimal rotation ages of the Faustmann model with fixed timber prices with a binomial option-pricing model when prices follow a diffusion process. Abildtrup (1999) examined the optimal thinning of forest stands from a real options perspective. Insley (2002) applied real options to model the optimal tree harvesting decision in forestry investments, highlighting the independence of the optimal harvest time from the current timber price and demonstrating the flexibility and comprehensiveness of the real options approach compared to traditional methods. Frey et al. (2013) explored the potential of forestry systems, emphasizing the importance of flexibility in decisions. The results indicated lower feasibility in adopting these systems when considering flexibility and variability in real-world decision-making scenarios. However, these studies do not extend the real options approach to assess the values of the range of managerial flexibility that may be available to farmers who could enter strategic partnerships for selling carbon credits with managers of companies needing (or wanting) to reduce their greenhouse gas emissions.

3. Methodology

The methodology section provides a detailed overview of the steps taken to make the proposal presented in the study tangible. First, we introduce the proposal for the practical implementation of the BTS model adapted to the agricultural context. Next, we present the proposal for pricing the flexibility associated with marketing cattle with the "green cattle" certificate using the real options model.

3.1. Adapting the BTS Model to the Agricultural Context

This section proposes the adaptation of the BTS model to the agricultural scenario, where a rural producer and a partner company seek to establish a strategic collaboration through carbon credits. Figures 2 and 3 illustrate the base model and the proposed model, respectively.

Figure 2 shows the original model, in which the producer does not have access to the partnership with an industry company. In this scenario, the producer is responsible for purchasing the land, investing in the property (such as common farming structures, fencing, corrals, machinery, among others) to make the farm operational in the short run. Hence, the producer is responsible for negotiating with the banks for the necessary loan to implement its own project specifications. Although there is a specific line of credit for farming in Brazil, the terms of this financing may vary according to the bank's perceived risk for the producer and operation.

Maiangwa (2012) explores that rural businesses rely on loans for their daily operations, and it is crucial for their development. According to the author, although sustainable financial services are crucial to improving productivity and expanding operations, most of these producers do not have access to the correct credit lines, and he states that poor people usually have limited access to credit. Peskett (2010) analyzes the impact of carbon credit financing on the opportunities for local producers based on a case study in Uganda. The author states that it is necessary to balance the needs of both project financers with the producers and the community involved in the project. The author relates some of the projects' financing aspects with the ranchers' risks and opportunities. Borbora (2014) analyzes the value chain in agriculture and emphasizes the importance of financial services for the improvement of rural producers. According to the authors, farmers are moving to different sectors due to lower returns, which can be improved by different market and financing conditions to produce value.

Paiva et al. (2020) show a viability study of cattle breeding in Brazil. The authors state that agriculture has huge viability in the country, especially in the livestock sector, and plays a significant role in the Brazilian economy and the international cattle market due to its better productivity ratios. Nevertheless, Nascimento et al. (2007) state that Brazilian farmers struggle to access adequate financing. The authors describe the types of Brazilian financing for this type of property and state that one of the reasons rural producers fear financing is due to its high-interest rates, short maturity, and price fluctuation.

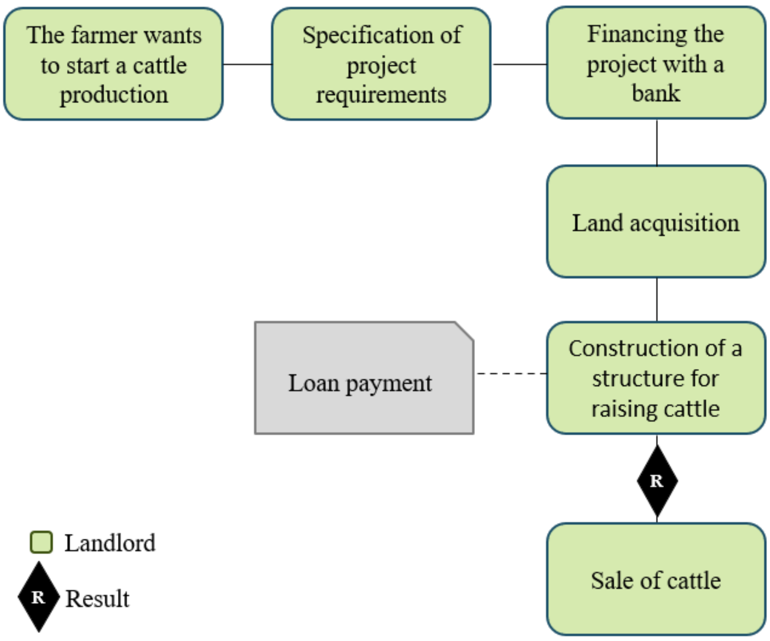

Figure 2: Flowchart of base model.
Source: Elaborated by the authors.

Figure 3 shows the proposed model. We propose an adaptation of the BTS contract, originally used only for the real estate scenario, to the agricultural scenario. We suggest a partnership with a company in the sector (such as a food/beef company). In this scenario, the rural producer takes a credit line with the banks to purchase and develop the projects, but a part of the land is rented to the company that aims to offset its emissions. This portion of the land is used for reforestation, and the farmer is responsible for building the structure for the reforestation to take place. The carbon credits generated in the project are divided between the farmer and the company. The strategic collaboration is structured through a build-to-suit contract. It is assumed to be a 20-year contract, as build-to-suit contracts are usually long-term.

The proposed model allows the company to reduce of even offset its emissions, generating carbon credits through a fixed rental payment for the farmer's land. Additionally, the company can focus on its core business, and the construction and maintenance of the reforestation project are the farmer's responsibility due to the build-to-suit contract specifications. Although it's difficult to measure the impact of neutralizing its emissions, a few authors relate the cost of debt to the level of carbon awareness of the company and associate good carbon risk management with the firm's success (Jung et al, 2018).

The farmer receives additional revenues from part of the issued carbon credits and the rental paid by the company. Besides that, the farmer would also sell its cattle at a premium, considering that the product is green. Although it's challenging to price the exact premium that a consumer would pay for green cattle based on the current literature review, Katt and Meixner (2020) discuss the influence of organic products on consumer willingness to pay. The authors concluded that organic produce can be worthwhile for producers despite the additional costs. Janssen and Hamm (2012) also conclude on a positive effect of the organic label on consumer willingness to pay, based on an experiment conducted in six European countries. Besides that, the strategic partnership may alter the perception of risk of the banks to the rural producers and change their cost of debt.

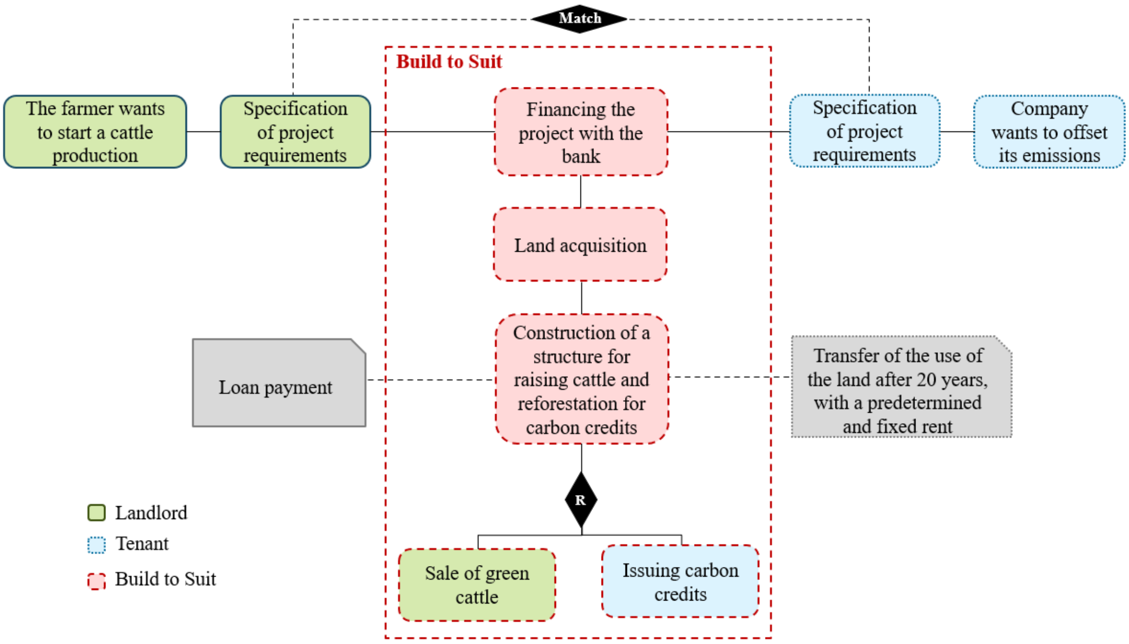

Figure 3: Flowchart of build-to-suit model.
Source: Elaborated by the authors.

3.2. The Real Options Model

Traditional methods to assess investments are characterized by a lack of flexibility when implementing the project. Some methods, such as the NPV (one of the most common expressions employed in project appraisal), are not able to consider the value of the operative flexibility when managing a project. The well-known expression of the NPV is given by Eq. (1).

$$NPV = -I_0 + \sum_{k=1}^{n} CF_k \prod_{j=1}^{k} \left(1 + i_j\right)^{-1} + RV_n \prod_{k=1}^{n} (1 + i_k)^{-1} \tag{1}$$

Where I_0 is the initial investment at the present moment, CF_k is the expected cash flow corresponding to period k, where $k = 1, 2, \dots, n$. i_k is the interest rate corresponding to period k, and i_j is the interest rate corresponding to period j, where $j \leq k$. RV_n is the residual value of the project at moment n.

The NPV method has many limitations since its main parameters are of a random nature (Rambaud *et al.*, 2017). Thus, in this paper, the value of the analyzed project is represented by the so-called expanded net present value (eNPV) in Eq. (2).

$$eNPV = NPV + ROV \tag{2}$$

where the net present value NPV is the discounted value of all expected cash flows that the project generates. The real option value (ROV) represents the value of the flexibility.

We consider an investment opportunity allowing management to expand the project's scale by a fraction α at time T by making an investment outlay of A. Let X denote A/α. In order to capture the expansion situation (call option), we introduce the parameters $\omega = +1$.

We assume a non-deterministic future cash flow structure; more precisely, as usually in ROA, we suppose that the gross project value V follows a geometric Brownian motion. For the sake of simplicity, the drift rate and the instantaneous standard deviation of V_t are supposed to be constant μ and σ.

Under stochastic prices, if the BTS is delayed until the next period, the owner faces uncertainty over whether prices will be higher or lower than the current period. Suppose the price of cattle, P_1, and the carbon credit price, P_2, follow the stochastic process in Eq. (3).

$$dP_i = a_i(P_i, t)dt + b(P_i, t)dz \tag{3}$$

where the drift term, $a_i(P_i, t)$, $i = 1,2$, and the variance term, $b_i(P_i, t)$, are known nonrandom functions and $dz = \varepsilon_t\sqrt{t}$ is the increment of a Wiener process, where ε_t is $N(0,1)$ and $E(\varepsilon_t\varepsilon_s) = 0$ for $t \neq s$. The BTS decision can be specified as an optimal stopping problem solved using the technique of dynamic programming (see Dixit and Pindyck, 1995). Let revenue be denoted by $R = Q \cdot P$, where Q is the constant amount of cattle or carbon capture, and P follows Eq. (3).

When the call option is presented in the project, then, just before the expiration of this option, the investment opportunity's value would be as presented in the Eq. (4).

$$V + \max\big((\alpha V - A)\omega, 0\big) = V + a \cdot \max((V - X)\omega, 0) \tag{4}$$

In other words, the present value added to the base-scale project by the option to expand at time T is $\alpha F^{(1)}(V, T, X, \omega)$, where $F^{(1)}(V, T, X, +1)$ denotes the present value of an American call option with maturity date T and exercise price X.

The Bellman equation is given below (Eq. 5), where $V(R, t)$ is the value of the BTS option at time t:

$$V(R, t) = max[R(t) - A; (1 + \delta\Delta t)^{-1}E(V(R + \Delta R, t + \Delta t))] \tag{5}$$

In Eq. (5), $R(t)$ is the total revenue from selling green cattle and carbon credit time t, A is the additional costs, and δ is the instantaneous discount rate. For each t there will be a critical value of revenue, R^*, such that changing to BTS is optimal if $R < R^*$, while not changing is optimal if $R > R^*$. The solution involves finding the free boundary, $R = R^*(t)$.

Following standard arguments Dixit and Pindyck (1995), taking the limit as $\Delta t \to 0$, and applying Ito's Lemma, from Eq. 5 we derive a partial differential equation satisfied by the value function in the continuation region as shown in Eq. (6).

$$\delta V(R, t) = V_t + [a(R, t)Q + QR(t)]V_R + \frac{1}{2}b^2(R, t)Q^2V_{RR} \tag{6}$$

The optimal stopping problem Eq. (5) will now be respecified in a form that is more conducive to valuing an American-type option with a free boundary. Two alternate formulations are the variational inequality formulation and the linear complementarity formulation. The theory of variational inequalities has been used to show that the American option problem is well posed, in that it has a unique solution. Both the linear complementarity and variational inequality formulation eliminate any explicit dependence on the free boundary; the free boundary can be recovered after the option valuation problem is solved (Wilmott et al., 1993).

In order to formulate the BTS problem as a linear complementarity problem, we write Eq. (6) as follows in Eq. (7), with τ defined as "time remaining", $\tau = T - t$,

$$OBTS = \delta V(R,\tau) + V_\tau - \frac{1}{2}b^2(R,\tau)Q^2V_{RR} - [a(R,\tau)Q + QR(\tau)]V_R \tag{7}$$

The linear complementarity problem can now be specified as Eq. (8).

$$\begin{cases} OBTS \geq 0 \\ V(R,t) - (R-A) \geq 0 \\ OBTS\big(V(R,t) - (R-A)\big) = 0 \end{cases} \tag{8}$$

This formulation can be seen as a description of the rational individual's strategy when holding an American-type option. Part *i* of the linear complementarity problem specifies that the required return (δV) less the actual return from not expanding will be nonnegative. If $OBTS = 0$ then the required return from holding the option equals the actual return, and it is optimal to continue holding the option. If $OBTS > 0$, then the required return exceeds the actual return, implying that the option should be exercised. The case of $OBTS < 0$ implies that the actual return exceeds the required return, a situation we would not expect to persist in competitive markets. Part *ii* of the linear complementarity problem states that the value of the option, $V(R,t)$, can never go below the value of keep the cattle production, $(R - A)$. This follows from the fact that the option to harvest can be exercised at any time. If the value of the option falls to the level of the payout, it would be immediately exercised, and thus would never go below the value of the payout. Part *iii* states that either i or ii or both will hold as a strict equality. If $OBTS = 0$, then traditional cattle production is optimal; if $V(R,t) - (R - A) = 0$, then it is optimal to cut. If both are identically zero then the value of green cattle equals the value of traditional cattle, and the owner would be in theory indifferent to either option.

For a numerical solution of Eq. (8) we must specify the boundary conditions. Note that because the linear complementarity formulation does not depend explicitly on the free boundary we do not have to specify the value matching and smooth pasting conditions. Rather, these conditions are a consequence of this formulation (Friedman, 1988).

Boundary Condition 1. For nonzero values of Q, as $R \to 0$ it must be the case that $P \to 0$ since $R = Q \cdot P$. From Eq. (2), in order to prevent negative prices, we must have $b \to 0$, as $P \to 0$ and $a \geq 0$ as $P \to 0$.

Boundary Condition 2. As revenue, R, gets very large, a boundary condition that seems intuitively reasonable is $V(R,\tau) = \gamma(\tau)R$ for some function $\gamma(\tau)$. As R approaches infinity, there is little further upside potential for the option due to capital gains on the standing forest. It is therefore assumed that the value of the option is proportional to R. This implies that $V_R = \gamma(\tau)$ and $V_{RR} = 0$.

Terminal Condition. As the time remaining approaches zero, the value of the option is the revenue from BTS, $V(R, \tau = 0) = R - A$.

The numerical algorithm for determining the value of the option involves the discretization of the linear complementarity problem Eq. (8) using an implicit finite difference method (see Insley (2002) for details).

This paper uses the method of simulation for calculating option values. Asset pricing simulation methods, introduced to finance by Boyle (1977), involve calculating option values by simulating thousands of potential future scenarios for uncertain variables, often utilizing Monte Carlo simulation (Mun, 2006a). These simulation methods are commonly applied to real options problems by creating a distribution of expected future asset values (Boyle, 1977). Additionally, simulation in real options models can serve as a foundation for model inputs such as volatile prices or discount rates (Mun, 2006b).

Monte Carlo simulation holds a principal advantage over other valuation techniques due to its capacity to handle multiple uncertainties, especially those with non-standard distributions, changing distributions, or correlations (Triantis, 2003). This method proves particularly useful for problems characterized by path dependency, where future decisions or outcomes are contingent on decisions made at earlier points in time (Longstaff and Schwartz, 2001; Triantis, 2003).

4. A case study

In order to demonstrate the insight that simulation based real options models can provide, we used a ROA simulation method to analyze how accounting for multiple sources of risk influenced the threshold prices necessary to induce farmers change from cattle to “green cattle” in southeast Brazil. The risks modelled in this hypothetical case study are limited to price risk, however the method could be extended to include multiple risk including yields, costs and interest rates using probability distributions or stochastic processes.

4.1.Decision scenario

In this example, we consider a farmer's decision to buy land to raise cattle. In this case, the farmer is presented with two alternatives. First, he can opt for monoculture, facing the risks and uncertainties of the livestock market. Secondly, he can opt for a strategic partnership with a company that wants to offset its carbon emissions and sell “green cattle” in the market. In this case, the producer integrates cattle farming with carbon credits according to the BTS and ROA's investment rules.

We assume a small farmer that is located in Minas Gerais, Southeast Brazil. This area is characterized a diversity of geographical and topographical features in its terrain, marked by extensive mountainous areas. The variety of the terrain and the richness of the soil influence the variety of economic activities in the state, including livestock, mining and tourism.

In addition, we assume a food company that exports beef in South America and also operates in the industrialized segment, selling its products to other countries. This company faces emission challenges in its operations. Beef production contributes to greenhouse gas emissions through enteric fermentation and waste management, while livestock expansion can lead to deforestation. Energy-intensive industrial processes and long-distance transportation increase carbon emissions.

4.2.Data and model assumptions

To calculate the value of the option to sell "green cattle," we projected the rural producer's cash flow in real terms, disregarding inflationary effects. The cash flow was projected in Brazilian reais and then converted to US dollars, considering an exchange rate set by the Central Bank of Brazil of R$5.22/US$ in December 2022. We considered a projected period of 20 years, which is the length of the build-to-suit contract.

The price associated with the cattle was based on the future prices of cattle negotiated on the Brazilian stock exchanges (B3), calculated in partnership with CEPEA (*Centro de Estudos Avançados em Economia Aplicada*) as of the valuation date, considering a real growth rate during the projected period. The resulting NPV, according to ROA, must have the same value as the average of Monte Carlo simulation results. It was considered three complete cycles per year, with an average of one cattle per acre. The property is focused on cattle breeding and selling the living cattle after reaching the adequate age. The property does not have any slaughtering activity.

The costs considered are associated with feed costs, overhead, animal medical care, labor, gas, and general maintenance, which were obtained from a local Brazilian farmer and have fixed characteristics. General expenses of 5% of net revenue were considered. The direct and indirect taxes considered in the model follow the Brazilian current tax legislation as of the valuation date and the effective tax rate paid by a small producer in the state of Minas Gerais.

The initial investment consists of the purchase of land in the state of Minas Gerais, approximately 1,000 acres, and initial infrastructure (corrals, furniture, utensils, machinery, and equipment, among others). From year one onwards, the investment consists of heifer acquisition and replacement of the existing fixed assets, according to their depreciation. The depreciation rates followed the Brazilian current legislation. Table 1 shows the projected investments in the property. Additionally, pre-operational expenses with land preparation, licenses, and others were considered.

Table 1: Model parameters under consideration.

Description	Value
1. Initial Investments	**304**
Land (US$ thousand)	286
Infrastructure (US$ thousand)	18
Pre-Operational Expenses (US$ thousand)	153
2. Biological Asset’s investment	**231**
Cycles (per year)	3
Value per cycle (US$ thousand)	77
Weight @	16@
3. Revenue	
Number of cattle sold per cycle	1,000
Tons of carbon per tree planted	0.14
4. Taxes	
Tax on revenue	13%
Tax with rural benefit	0,3%
5. Costs and Expenses	
Unitary costs per cycle (US$ thousand)	239
Pre-Operating Expenses	153
SG&A (%net revenue)	5%
Issuing certification (US$ thousand)	89
Monitoring of carbon credit	3%
6. GBM	
Sigma cattle	14%
Sigma carbon	46%
Initial price of cattle (US$/arroba)	48
Initial price of carbon credit (US$)	2.59

Source: Elaborated by the authors.

To calculate the option value of the expanded model, we considered a scenario in which the rural producer would bear direct costs for reforestation and land preparation. Table 2 shows the parameters adopted in the analysis and which will be sensitized next. The farmer would sell its "green cattle" for a higher price, with a base premium assumed at 7%. In the risk analysis section, the authors present a sensitivity analysis of this parameter. The farmer receives the build-to-suit rental from the partnership with the company and a share of the carbon credits produced on its land. We assume a profitability of the build-to-suit contract at 1% per month, related to the size of the land and initial investments, commonly adopted in real estate build-to-suit Brazilian contracts. The share of the carbon credits adopted in the base scenario is 20%. There variables are sensibilized in the risk analysis section.

To estimate the future prices of cattle and carbon credits, we assumed that Brazilian cattle prices and carbon pricing follow a stochastic process. To estimate the parameters described in Eq. (1), a historical series of Brazilian cattle prices (made available by Brazilian stock exchanges in partnership with CEPEA) and future prices of carbon from the CBL Nature-Based Global Emissions Offset, traded by the CME Group, were used.

Table 2: Expanded model parameters under consideration.

Parameters	Value
Build-to-Suit (US$ thousand/year)	89
%ESG farmer	20%
Green cattle premium	7%
Reforestation costs (%net revenue)	1%

Source: Elaborated by the authors

The discount rate used in the analysis was of 12.48%, as standard in rural property feasibility models. The Brazilian real interest rate is 6.34% according to data from the Central Bank. Other Brazilian authors considered in the livestock valuation a discount rate equal to the Brazilian interest rate (Paiva *et al*., 2020), while Barbieri *et al*. (2016) and Garcia *et al*. (2017) and Simões *et al*. (2007) adopted a 6% discount rate, and Oliveira and Couto adopted a 6.17% discount rate. Gollo *et al*. (2017) adopted a 15% discount rate, based on the investor required return rate. Nishi *et al*. (2007) adopted a 10% discount rate. The authors explored the economical viability of three projects of reforestation in Brazil, considering the impact of carbon credits on this projects. The adopted discount rate of 10% is recommended by the Center for Integrated Studies on the Environment and Change Climate of the Brazilian government, which deals with proposals and eligibility of carbon credits projects in Brazil.

All the costs are similar to the adopted by international and Brazilian authors. (Ashraf, 2013; Dovie *et al*., 2006; Paiva *et al*., 2020; Barbieri *et al*., 2016; Gollo, 2017; Simões *et al*., 2007; Garcia *et al*., 2007; Taninaka *et al*., 2015; Moreira *et al*., 2009; Tupy *et al*., 2020 and Oliveira and Couto, 2018).

4.3.Results and discussion

Based on the NPV quantification, the project is considerable viable. Figure 4 shows the results for the base model estimated with the traditional NPV analysis. The results are an expected NPV of US$ 9,321 thousands and an internal rate of return of 38.79% and to delay the investment. There’s a 9.2% of chance that the NPV is negative, that is, that the expected return is lower than the cost of capital. The Figure 2 shows the value ate risk of the operation. Considering that the land is 1,000 acres, the values show a NPV of US$ 9,321/acres.

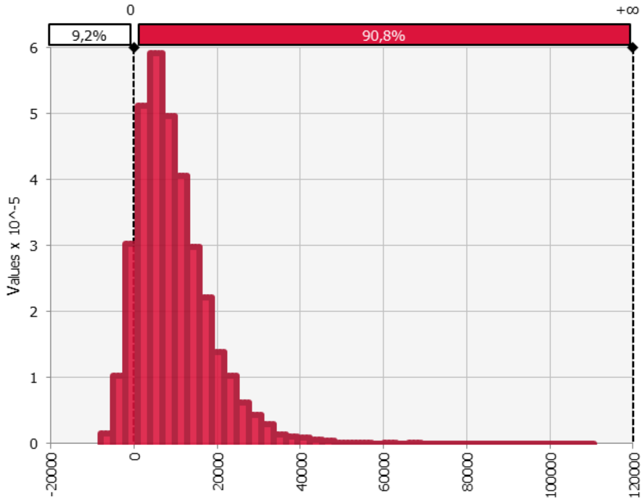

Figure 4: Result of the base model.
Source: Output from @Risk.

Figure 5 show the results for the expanded model estimated with the ROA analysis. The results are an ENPV of US$ 23,698 thousands. The implicit IRR of the project goes to 46,04%. The level of uncertainty decreases to 2.7% (value at risk). Considering that the land is 1,000 acres, the values show a NPV of US$ 23,698 /acres.

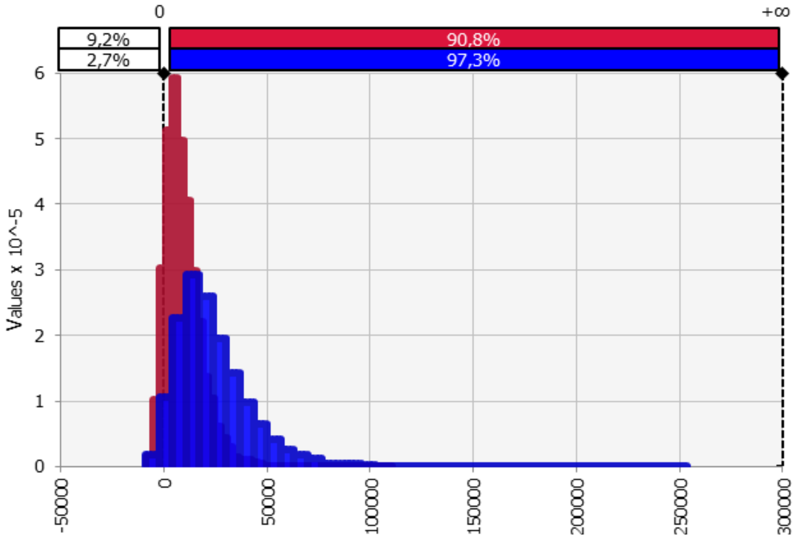

Figure 5: Comparison of results with and without option.
Note: Red graph = traditional model; Blue graph = expanded model.
Source: Output from @Risk.

The findings shows that the expanded model, considering the strategic partnership with a company's sector, brings positive results to the farmer. Monte Carlo simulation shows that the level of uncertainty to the local farmer drops to 2.7% in a possible partnership. Additionally, the ENVP was much higher than the scenario without the partnership.

Nishi *et al.* (2007) has shown a positive return for common reforestation projects in Brazil. State of São Paulo, with return rates between 9.60% and 15,50% and NPVs between USD 17.59 to USD 647.02 per acre. Taninaka (2015) presented a viability of cattle breeding (Wagyu type) in Brazil by analyzing its positive operational projected margins. Garcia *et al.* (2017|) has shown a cattle viability analysis and the results pointed to a internal rate of return varying from 6.1% to 7.3%. Additionally, the authors calculate the financial risk of the projects higher than 76% when sensitizing the discount rate to 10%, but a financial risk only until 10% with a discount rate of 6%. Simões *et al.* (2007) evaluated cattle breeding in Brazil using Monte Carlo simulation. It was concluded that the probability of a negative margin is 28%. Paiva *et al.* (2020) has explored the financial viability of cattle breeding the state of Goias, Brazil through a 15-year period. Due to the high investments needed in the case, the project was not considered viable (internal rate of return of 1.27%). Barbieri *et al.* (2016) presented a financial viability of feedlot beef cattle in the state of São Paulo, Brazil. The operational margin was 68% and the return rate was 10.91%. Overall, the finding of this study has shown a better profitability than the described Brazilian literature. It can be explained by both the partnership, the combination between a reforestation project and cattle breeding.

If the producer waits one year before entering the market, the option will be worth 26,315 thousand dollars, showing that it's beneficial to the rural producer to delay the investment, but has higher level of uncertainty than the expanded model (4.9%). Figure 6 shows the result of the model for this case.

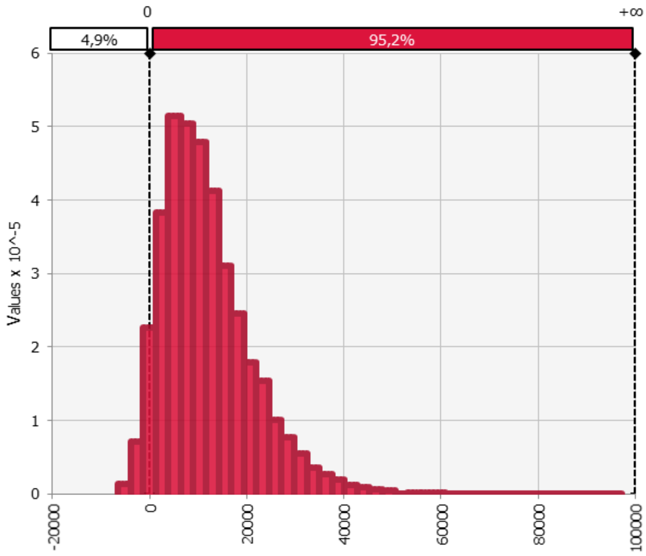

Figure 6: Comparison of results with and without option.
Note: Red graph = traditional model; Blue graph = expanded model.
Source: Output from @Risk.

5. Risk Analysis

Risk analysis plays a key role in evaluating the innovative proposal that combines the BTS model adapted to the agricultural context and participation in the carbon credit market. Risk analysis plays an important role in evaluating the proposed model, as it offers an in-depth understanding of the inherent variables and uncertainties, allowing for a more informed approach to potential challenges. This analysis not only identifies sources of vulnerability, but also provides strategic insights for effective risk mitigation, strengthening the resilience of the proposed model. The Figures 7 to 10 shows the impact of the sensitivity analysis for each parameter on the expanded model.

The discount rate usually plays a key role on the valuation model. As the expanded model uses the Brazilian interest rate, it may alter in a short period of time due to economic instability and changes in the macroeconomic scenario. Other than that, Brazilian authors may differ on the use of the discount rate in a reforestation or cattle breeding project. The use of the discount rate adopted by Nishi *et al.* (2007), may also be adequate to the evaluated project, once it's recommended by the Center for Integrated

Studies on the Environment and Change Climate of the Brazilian government, which deals with proposals and eligibility of carbon credits projects in Brazil. It's important to emphasize that this is not only a reforestation project, once it's also a cattle breeding valuation. Thus, it's also important to observe the impact of discount rates used in agriculture project that evolves cattle different od the Brazilian interest rate such as in Garcia *et al.* (2017) and Simões *et al.* (2007), who adopted a 6% discount rate, and Oliveira and Couto, who adopted a 6.17% discount rate. Additionally, it's important to observe the impact of a change in the discount rate, once the required return may be different to each investor.

Figure 7 shows that the Project is still economic viable when applying a discount rate between 3% and 9%. Nevertheless, the sensitivity shows that to discount rates higher than 7% the option value is zero, considering that the ENPV is lower than the base ENPV.

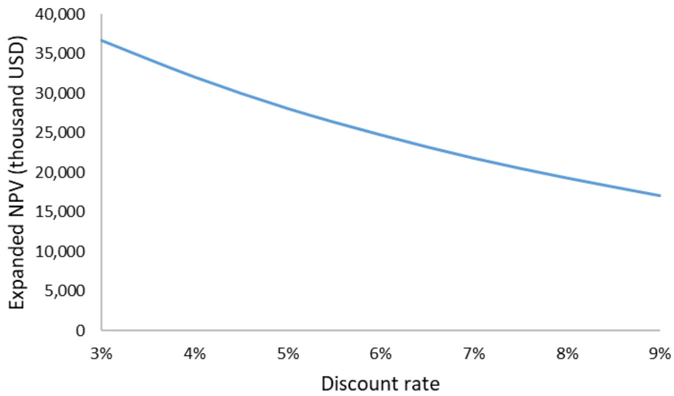

Figure 7: Sensitivity to the discount rate.
Source: Elaborated by the authors.

As indicated in the literature review, the influence of organic products has a positive effect on consumer willingness to pay. Nevertheless, there's not an exact calculation of how much it would affect the willingness to pay, and therefore, the product prices. Considering this, it's expected the "green cattle" premium caries uncertainty and therefore it was made a sensitivity analysis. Figure 8 shows that the "green cattle" premium plays a crucial role on the valuation. Result of the ENPV varies from US$ 21,919 thousands to USD 27,090 thousands. As expected, the option value for the premiums lower than 7% are zero, resulting in an ENPV lower than the base ENPV.

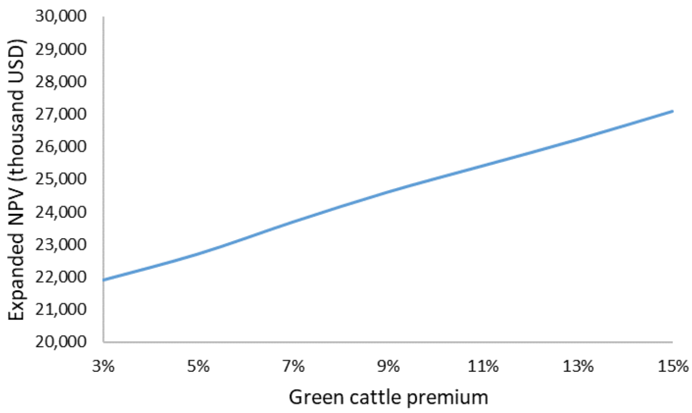

Figure 8: Sensitivity to the Green Cattle premium.
Source: Elaborated by the authors.

Figure 9 shows the sensitivity analysis of the build to suit profitability. The ENPV hasn't shown a high sensitivity in the valuation. The ENPV varies from USD 23,598 to 23,798 thousand. It's observed that the green cattle premium and the %ESG are much more important to the farmer's profitability. The build to suit contracts can be observed in several real estate investment funds in Brazil, presenting different profitability, hence the authors have performed the sensitivity.

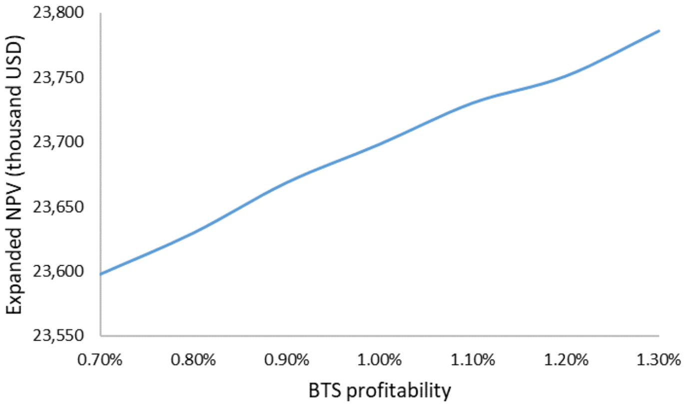

Figure 9: Sensitivity to the BTS
Source: Elaborated by the authors.

Figure 9 shows the impact of the amount of carbon credits that will be transferred to the farmer in the partnership with the Company. The other part of the carbon credits stays with the company. We named this variable as % ESG. While there is literature on the benefits of company disclosure on the impact of carbon awareness on the company's cost of capital (Jung *et al.*, 2018), the percentage of carbon credits that would remain with the farmer in a possible partnership is an uncertainty. The value of the ENPV has changed approximately 4% in the sensitivity scenarios.

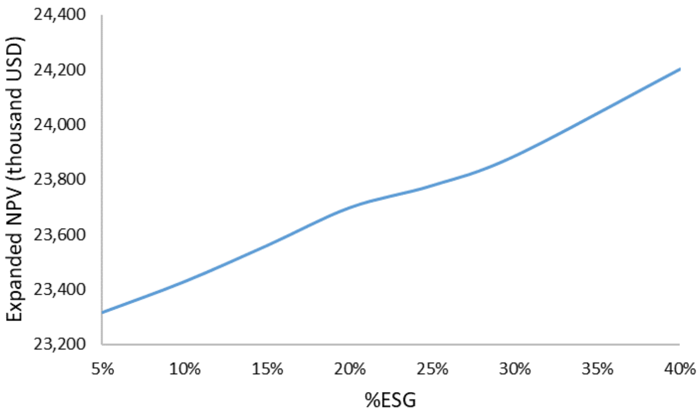

Figure 10: Sensitivity to the %ESG.
Source: Elaborated by the authors.

Table 3 shows the option value result for the sensitized parameters. The option value is zero when the ENVP of the sensitivity is lower than the base ENPV.

Table 3: Summary of option value in sensitivity analysis.

Discount rate	Option Value (USD thousands)	Green cattle premium	Option Value (USD thousands)
3%	12,981	3%	0
4%	8,365	5%	0
5%	4,386	7%	0
6%	1,056	9%	919
7%	0	11%	1,721
8%	0	13%	2,528
9%	0	15%	3,392
%ESG	**Option Value (USD thousands)**	**BTS profitability**	**Option Value (USD thousands)**
5%	0	0,7%	0
10%	0	0,8%	0
15%	0	0,9%	0
20%	0	1,0%	0
25%	80	1,1%	32
30%	188	1,2%	53
40%	502	1,3%	88

Source: Elaborated by the authors.

6. Policy implications

Worldwide, governments are employing public policies to enhance environmental results, including the reduction of greenhouse gas emissions or the preservation of habitats (Bryan and Crossman, 2013). Nevertheless, projects involving carbon forestry offsets are bound to incur substantial initial costs, generate revenue gradually over decades, and are notably vulnerable to regulatory shifts. Due to these inherent risks, despite a positive NPV, such investments may not be deemed attractive (Polglase *et al.*, 2011, 2013). The analysis employed in this paper reveals substantial opportunities for carbon markets to stimulate profitable carbon bio-sequestration and promote biodiversity outcomes through the reforestation of agricultural lands.

For policymakers looking to accelerate land use change to address challenges such as climate change, the implications of ROA are clear. Given the uncertainty surrounding carbon price trajectories and the costs of entering this market, landowners have a strong incentive to postpone afforestation and reforestation, either to allow uncertainties to settle in or to capitalize on potentially higher future carbon prices. This result significantly decreases forest mitigation efforts in the short term (Lubowski and Rose, 2013). ROA can provide better guidance to policymakers regarding the necessary level of incentives and the most effective incentive policy structures to reduce intertemporal opportunity costs. This, in turn, increases the likelihood of achieving the desired outcomes in terms of land use change.

While transitioning away from conventional agriculture is recognized for its broad environmental benefits, such as addressing dryland salinity (Bartle *et al.*, 2007; Wang *et al.*, 2008), soil erosion (Kort *et al.*, 1998), and potentially mitigating climate change effects, it is essential to consider unintended externalities caused by land use change. These externalities should be accounted for and valued wherever possible. Until now, ROA studies have given limited attention to incorporating non-market goods into land use change valuations. Their inclusion in future research would offer a more comprehensive perspective on the costs and benefits associated with land use change.

Applying ROA at an appropriate spatial scale, such as at a regional level, can provide more solid guidance for investment and support policy development. For example, a better understanding of how comparative advantages in livestock production in various regions affect the location and feasibility of issuing carbon credits. A better understanding of possible partnerships with agriculture could influence community support for alternative sectors.

7. Conclusion

In view of the challenges faced by small entrepreneurs in Brazil, this article proposes income diversification strategies for livestock farming. This article applies the real options model in a combination of structures between BTS models and the carbon credit market. This structure results in a strategic partnership between producers and companies, generating a sustainable business with the sale of carbon credits and the sale of "green cattle".

The application of the real options model in this context is carried out considering the uncertainties of cattle and carbon credit prices. Monte Carlo simulation is used to obtain the value of the option to expand cattle with a "green" certificate.

The results indicates that the proposed model can not only overcome financial obstacles but also create economic and sustainable opportunities. In addition, the results show that this approach provides a more realistic and adaptable analysis of the opportunities and risks inherent in the proposed model. The sale of carbon credits generated on the farm not only meets the growing demand for emissions neutralization, but also creates a virtuous cycle of sustainability and profitability.

The sensitivity analysis allows to observe the impact of other variables that carry uncertainty, as to observe different return rates. The variable that carries the most impact on the valuation (excluding the discount rate) and therefore on the farmer profitability, is the “green” cattle premium. The % ESG was also shown to be sensitive, and the adopted % in a possible partnership is uncertain. The BTS was shown to have a lower impact on the farmer profitability.

Overall, the project has shown a positive NPV for the base model, with a return rate of 38.79% and positive NPV of USD 9,322 thousands. The expanded model has shown much better results, with an ENPV of USD 23,698 thousands. It was shown a positive result to the farmer delay its investment. The results overall shown that the partnership is very positive to the farmer, especially due to the higher consumer willingness to pay for the green cattle, and the % ESG. An inspiration for future works is to explore the Company’s return in this type of partnership, in both the carbon credit selling and in the impact of the partnership, that would offset its emissions, in the Company’s discount rate.

This work offers a contribution to the intersection of sustainability and finance in the agricultural sector, providing a more holistic understanding of the economic opportunities emerging from this innovative partnership. For farmers, the proposal offers a strategy to overcome the financial and operational challenges associated with acquiring property and entering the carbon credit market, as well as providing an additional source of income through the "green" certification of livestock. For companies, the partnership offers a practical and sustainable solution for achieving their emissions reduction targets, in line with growing demands for socially responsible business practices. This represents an original contribution to the field of studies involving agricultural sustainability, rural finance and environmental practices.

This work can inspire future work and expand knowledge about economic dynamics in innovative agricultural scenarios. It is important, however, to circumvent the challenges in collecting data in the context of the carbon market due to its complex and dynamic nature. Future work could focus on creating more effective mechanisms for collecting and standardizing carbon market-related data, exploiting emerging technologies such as blockchain to improve transparency and traceability.

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