

## ANALYSIS OF THE ECONOMIC VIABILITY OF CENTER PIVOT IRRIGATION FOR MINAS GERAIS COFFEE CULTIVATION

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**ABSTRACT:** The use of irrigation in coffee cultivation is becoming increasingly common in various regions. Minas Gerais, the largest producer of Arabica coffee in Brazil, shows significant variability in its coffee production areas in terms of production systems and, especially, topography. The use of center pivot irrigation systems has been gaining ground in several regions of the state, and in some cases, even in slightly undulating terrain. This study aims to analyze the economic viability of using center pivot irrigation in Minas Gerais, considering its great variability. For this purpose, the Monte Carlo method was used to perform 5,000 simulations, taking as input data gathered from different sources, such as irrigation dealerships, consultants, and producers. It can be concluded that the selling price at the levels seen in recent years was the main factor that made irrigation viable in most simulations. Other parameters also influence viability, but to a lesser extent. The variation in electricity tariffs, for example, changes the percentage of viable simulations, but with less importance.

**KEYWORDS:** Monte Carlo simulation; Coffee production; Brazilian Coffee

## ANÁLISE DA VIABILIDADE ECONÔMICA DA IRRIGAÇÃO POR PIVÔ CENTRAL PARA A CULTURA DO CAFÉ EM MINAS GERAIS

**RESUMO:** O uso da irrigação na cultura do café vem se tornando cada vez mais comum em várias regiões. O estado de Minas Gerais, maior produtor de café arábica do Brasil, apresenta uma variabilidade muito grande em suas áreas de produção de café, em termos de sistemas de produção e principalmente topografia. O uso do sistema de pivô central vem se consolidando em diversas regiões do estado, e em alguns casos, mesmo em situações de relevo levemente

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acidentado. O presente trabalho tem como objetivo a análise da viabilidade econômica da utilização da irrigação por pivô central no estado de Minas Gerais, levando em consideração a sua grande variabilidade. Para isso se utilizou do método de Monte Carlo, para a realização de 5 mil simulações, tomando como dado de entrada informações levantadas de diferentes fontes, como revendas de irrigação, consultores e produtores. Pode-se concluir que o preço de venda nos patamares dos últimos anos foi o grande agente que viabilizou a irrigação na maioria das simulações. Outros parâmetros também influenciam a viabilidade, porém com menor intensidade. A variação da tarifa de energia, por exemplo, promove alteração na porcentagem de simulação que é viável, porém com menor importância.

**PALAVRAS-CHAVE:** Simulação de Monte Carlo; Produção de café; Café brasileiro

## INTRODUÇÃO

The arabica coffee production expected for the 2025/2026 harvest is estimated at 40.9 million bags (60 kilograms per bag) (USDA, 2025). Brazil it is the largest producer of Arabica coffee, accounting for 46.9% of the global production, and the second largest producer of Robusta coffee, accounting for 16.5% of the global production of this cultivar. Minas Gerais leads Brazilian Arabica coffee production, contributing over 69% of the national total. Given the state's wide array of climatic conditions, irrigation emerges as a crucial tool for ensuring consistent production and mitigating climate-related risks.

Irrigation has facilitated the expansion of coffee cultivation into previously inappropriate areas and has led to enhanced productivity (Silva et al., 2011). Moreover, its application is warranted even in traditional regions to alleviate the consequences of prolonged droughts during crucial periods of water requirement for coffee plants (Lima et al., 2008; Santos et al., 2020; Vicente et al., 2015). In the latest survey presented in the Irrigation Atlas (ANA, 2021), irrigated coffee in Brazil already appears prominently, with an area of almost 500 thousand hectares.

Irrigation helps guarantee production in diverse climatic conditions by eliminating water scarcity risk for the crop, but it comes with high costs. Center pivot irrigation systems, in particular, have a high initial purchase cost and considerable operating expenses, mainly due to energy costs (Lima et al., 2008; Silva et al., 2011). Based on a large dataset of coffee production in Minas Gerais, (Freitas et al., 2024) observed a growth of approximately 31% in irrigated

areas. This increase was attributed to the use of high-productivity cultivars and a greater planting density. The average yield for these irrigated areas was 50.5 bags of 60kg per hectare.

Considering the expansion of coffee farming and the concurrent rise in irrigation adoption in Minas Gerais' coffee sector, this work aims to assess the economic viability of center pivot irrigation for coffee production. The results can also be applied to other regions, provided they share similar technical and economic characteristics.

## MATERIAL AND METHODS

The methodology used was a Monte Carlo simulation, where random numbers generate values for specific variables. We assumed that the distribution of the variables involved was triangular, meaning each had a minimum, a modal value, and a maximum value. This technique is widely applied in various economic viability assessments, including the evaluation of irrigation system feasibility, as demonstrated by (Dhal et al., 2024; Ribeiro et al., 2024). We ran 5,000 simulations, considering the factors to be independent. Data was collected from diverse sources, including irrigation companies, consultants, and producers (Table 1).

Each randomly generated value ( $r$ , ranging from 0 to 1) was correlated with a variable's value within the triangular distribution and compared with the reference value  $r^*$  (Equation 1). If  $r > r^*$ , the simulated value is obtained by Equation 2; if  $r < r^*$ , the simulated value is obtained by Equation 3; and if  $r = r^*$ , the simulated value equals the modal value.

$$r^* = (m-a)/(b-a) \quad (1)$$

$$X_s = b - ((1-r)^*(b-a)*(m-m))0.5 \quad (2)$$

$$X_s = a + ((r^*(b-a)*(b-a))0.5 \quad (3)$$

Where,

$r^*$  = Reference value;

$X_s$  = Simulated value for each variable;

$a$  = Minimum value;

$b$  = Maximum value;

$m$  = Modal value.

While some of the parameters presented in Table 1 may exhibit interdependencies, such as the relationship between equipment cost reduction and its size when comparing projects within the same farm (Bonomo et al. 2000), these simulations are intended to represent the actual conditions encountered in the field. Our data collection from companies, consultants, and producers revealed a wide variety of production area types, differing in terms of topography, climate, and even production systems, particularly in Minas Gerais, a state of considerable size.

The economic viability of implementing a center pivot irrigation system for coffee cultivation was assessed using a benefit-cost (B/C) analysis. The investment was deemed viable when the benefits exceeded the costs, corresponding to a B/C ratio greater than 1. In this study, the only benefit considered was the productivity increase resulting from irrigation.

Other benefits, such as potential improvements in coffee quality that could command a higher market price, were not quantified due to the challenges in gathering the necessary data. Although some works such as (Pedroso et al., 2009) present positive results with the use of different water availability. The benefit-cost ratio (B/C) was determined by dividing the annual gross benefit of irrigation by the incremental annual cost incurred from irrigation use.

**Table 1.** Values used at Monte Carlo simulation

Parameter	Value		
	Minimum	Modal	Maximum
Central Pivot Acquisition Cost (R\$ ha <sup>-1</sup> )	16000	24000	42000
Economic useful life	10	15	23
Interest rate	9	10	14
Total installation cost (R\$ ha <sup>-1</sup> )	330	500	600
Irrigation requirement (h)	800	1000	1600
Energy demand (kW ha <sup>-1</sup> )	1.5	2	2.5
Energy Cost (R\$ kWh <sup>-1</sup> )	0.28	0.3	0.38
Increased productivity with irrigation bg ha <sup>-1</sup>	12	15	30
Selling price (R\$ bg <sup>-1</sup> )	880	1130	1380
production cost (R\$ bg <sup>-1</sup> )	500	622	745

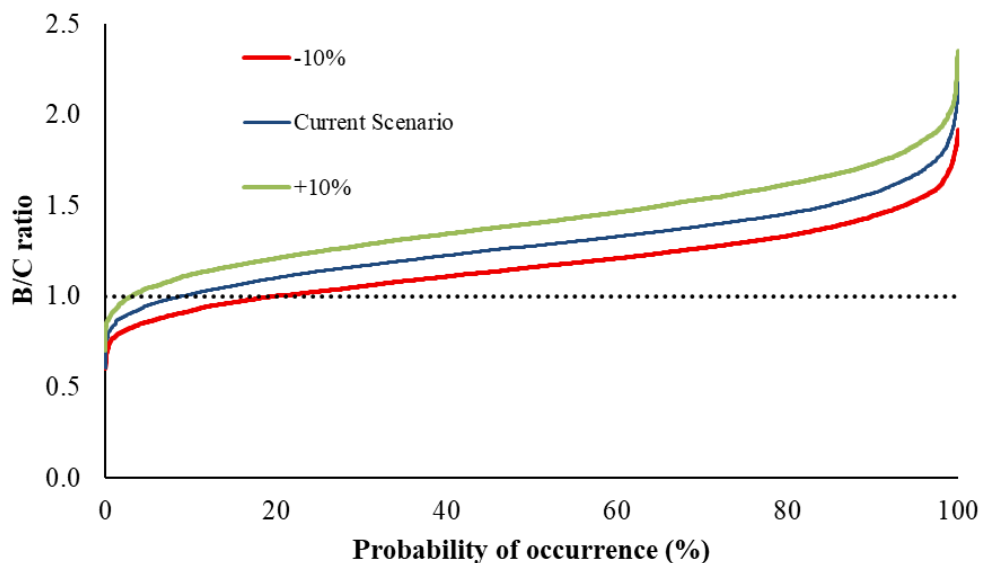
The selling price is a critical variable for the economic viability of an irrigation system. It must be sufficient to cover both standard production costs and the expenses associated with the system's installation and operation. For this analysis, the average annual prices from 2021 to 2024 were used to establish the current scenario, with the data obtained from the agricultural price series provided by the Center for Advanced Studies in Applied Economics (CEPEA).

The cost of labor specific to irrigation was calculated based on the number of irrigation hours required, using the methodology presented by Marques et al (2006).

## RESULTS AND DISCUSSION

Based on the data presented in Table 1 and considering that an investment becomes attractive when the B/C ratio exceeds 1, it was determined that irrigation was not viable in only 9% of the 5,000 simulations (Figure 1). It should be emphasized that the selling prices employed reflect those observed in recent years (2021 to 2024), a period during which coffee has seen market highs.

Figure 1 also shows that a  $\pm 10\%$  variation in the coffee's sale price is enough to change the viability distribution for implementing center pivot irrigation. A 10% average reduction in the coffee sale prices, as shown in Table 1, was sufficient to make nearly 20% of the simulations economically unviable. In contrast, a 10% increase in the sale price results in only 3% of the simulations being unviable. This demonstrates the strong dependence of viability on the sale price obtained by the producer; similar results were also found by da Silva et al. (2024).



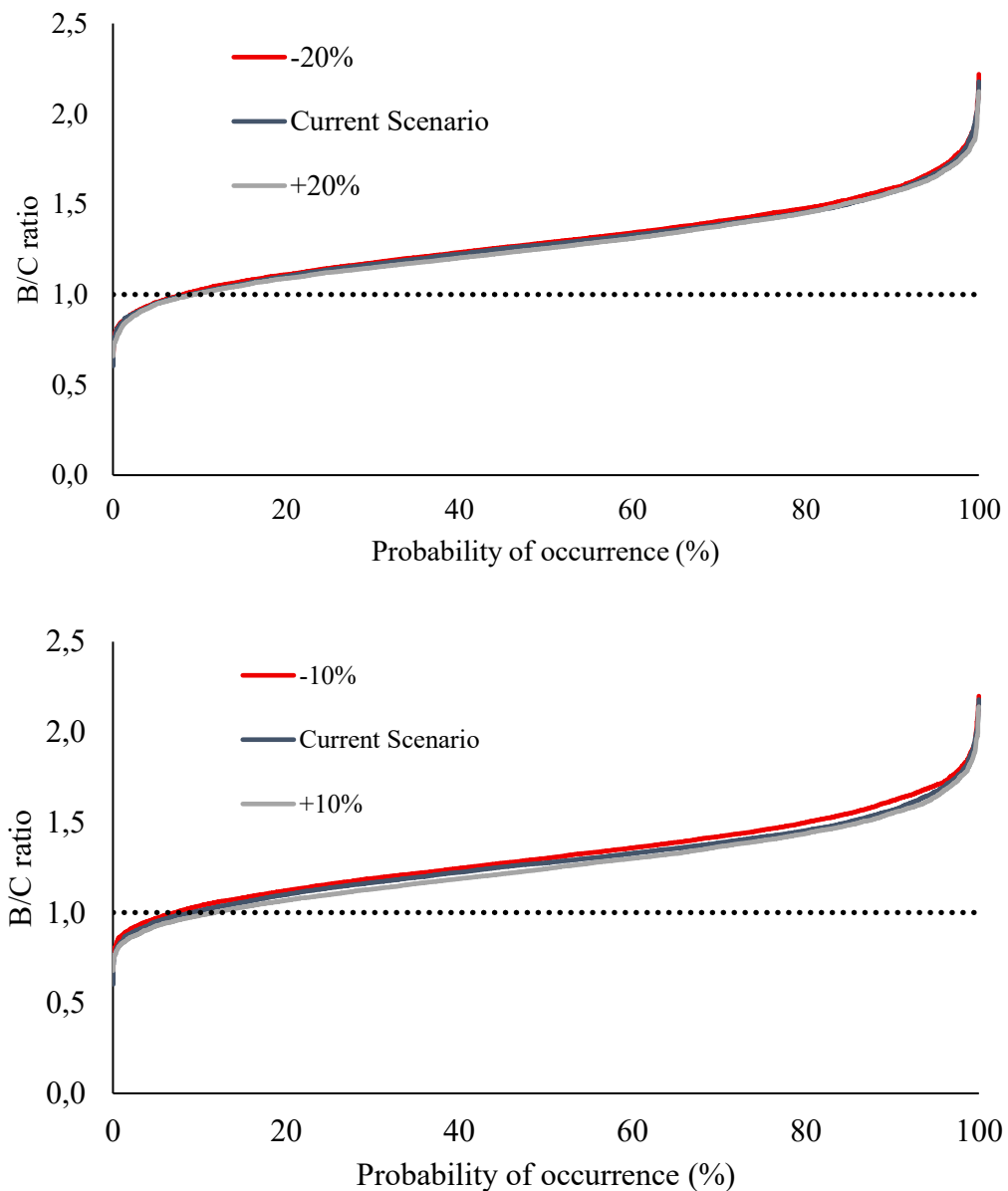
**Figure 1.** Benefit-Cost (B/C) ratio for the 5,000 simulations considering current scenario prices (2021/24) and considering a 10% increase and decrease in sales prices.

The energy cost, on average, accounts for 4.5% of the total cost of the irrigation system, based on the 5 thousand simulations using the data in Table 1. Considering the tariff's high susceptibility to temporal and especially increasing variation, a sensitivity analysis was performed with a  $\pm 20\%$  variation (Figure 2A).

Although the energy tariff is a significant parameter in the total system cost breakdown, a 20% variation, when utilizing the other parameters shown in Table 1, did not materially

impact the irrigation's viability. Even with a tariff increase on the order of 50%, the tariff's contribution to the total cost increases from an average of 4.5% to 6.6%, based on the 5,000 simulations.

The equipment acquisition cost was another factor assessed, with a simulated variation of  $\pm 10\%$ . What can be observed in Figure 2B is that a 10% increase in acquisition costs had less impact on viability compared to a 10% increase in the coffee selling price. In this scenario, the percentage of unviable simulations increased only from 9% to 11%.



**Figure 2.** Benefit-Cost (B/C) ratio for 5,000 simulations, showing the impact of current energy tariffs and a  $\pm 20\%$  change in energy costs (A) and showing the impact of center pivot acquisition cost and a  $\pm 10\%$  change in these costs (B).

The cost of labor specific to irrigation was, on average, only 1% of the total irrigation cost, with the highest shares around 2.2%. These values are similar to those found by Marques et al. (2006), who evaluated the use of different irrigation systems for sugarcane.

## CONCLUSIONS

Given the obtained results, it can be concluded that an increase in the coffee selling price had a more significant impact on the viability of irrigation implementation for this crop than other parameters, including increases in acquisition cost and energy tariff. Despite representing a substantial cost, an energy tariff increase of up to 20% did not render irrigation unviable for the majority of simulations, particularly when considering the selling price trends of recent years.

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