PRELIMINARY STUDY OF ECONOMIC FEASIBILITY OF A PROJECT OF AGGREGATES MINING THROUGH PROBABILISTIC ANALYSIS*

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Resumo

An economic feasibility study should consider parameters and uncertainties inherent in a project to produce consistent economic results, providing the investor a decision-making tool. This study aimed initially to carry out the conventional economic evaluation of the realistic scenario in the Mineração Megaípe Eireli, located in Pernambuco, whose Net Present Value (NPV) obtained was R$ 24,006,309.20, which represents a positive result. Through Monte Carlo methodology, a risk analysis was performed, considering uncertainties in 100,000 scenarios, in which nine variables assumed stochastic values within the defined domains, thus producing a statistical distribution of NPV instead of a single number, when a sensitivity analysis was performed to identify and quantify the variables that most impact the evaluation result. Finally, the two most influential factors identified in the initial sensitivity analysis were isolated and subjected to a new risk analysis in another 100,000 scenarios. It was concluded that the project is economically feasible and that the probability of generating profit for investors is 99.77%, although the probability of NPV being equal to or greater than that predicted by the conventional method is 49.98%.

Palavras-chave: Economic feasibility; Mine planning; Net presente value; Risk analysis.

ESTUDO PRELIMINAR DE VIABILIDADE ECONÔMICA DE UM PROJETO DE MINERAÇÃO DE AGREGADOS ATRAVÉS DE ANÁLISE PROBABILÍSTICA

Abstract

Um estudo de viabilidade econômica deve considerar parâmetros e incertezas inerentes a um projeto para produzir resultados econômicos consistentes, fornecendo ao investidor uma ferramenta de tomada de decisão. O presente estudo objetivou efetuar inicialmente a avaliação econômica convencional do cenário realista de uma mineração de agregados em fase de implantação localizada em Pernambuco, cujo Valor Presente Líquido (VPL) obtido foi R$ 24.006.309,20, o que representa um resultado positivo. Através da metodologia de Monte Carlo foi efetuada uma análise de risco considerando incertezas em 100.000 cenários, nos quais nove variáveis assumiram valores estocásticos dentro dos domínios definidos, produzindo assim uma distribuição estatística do VPL ao invés de um único número, sendo ainda efetuada uma análise de sensibilidade para identificar e quantificar as variáveis que mais impactam no resultado da avaliação. Por fim, os dois fatores mais influentes identificados na análise de sensibilidade inicial foram isolados e submetidos a uma nova análise de risco em outros 100.000 cenários. Foi concluído que o projeto é economicamente viável e que a probabilidade de gerar lucro aos investidores é de 99,77%, embora a probabilidade do VPL ser igual ou maior que o previsto pelo método convencional seja de 49,98%.

Keywords: Viabilidade econômica; Planejamento de lavra; Valor Presente Líquido; Análise de risco.

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1 INTRODUCTION

The study of a mining project generally involves three stages, which are conceptual, pre-feasibility and feasibility studies. However, for progression to the last two phases, it is necessary to define a production schedule and a lifetime expectancy, although some of the information about mining is still conjecture. In theory, it would be possible to calculate the optimal extraction rate of a given orebody from the knowledge or inference of its total mass and the distribution of grades (including the effects of variation of the cut-off grade), as well as all costs and sale prices of the products through the mine life. This information, however, is not available at an early stage of project, neither is it fully elucidated during mining, and may possibly not be obtained accurately even in the closure of the mine [1,2,3].

Choosing reduced production rates extends cash flow, postpone revenues and sacrifices potential profits that are restricted and attained only after many years of enterprise. Conversely, high production rates substantially increase capital costs, even though they tend to maximize the project's financial return, and could not even recover the investment due to the short lifetime, and eventually result in higher production than the market's absorptive capacity. In practice, a production rate is limited by the space available for operations. Much of the mine pit geometry allows the production increase, since the mining fronts are made available as the pit is exploited [2,3].

The selection of the mining method is also a critical process for the project, and this selection should consider the interaction of technical, technological, economic, social, political, environmental and historical factors, as well as subjective criteria and the uncertainties inherent to each of these factors, whose main objective is to obtain a method that maximizes the profit of the project and also the recovery of the mineral resources. Once selected, the method should ensure adequate labor conditions, encourage the reduction of impacts to the environment, allow the stability of the mine during its lifetime and be flexible to the geological conditions and the available infrastructure, allowing maximum productivity to be achieved and unit and global production costs reduction [4,5].

An economic feasibility study should consider all these variants and produce results for several scenarios, in which are evaluated the possible mining methods, different cut-off grades, mining and processing equipments, production rates, ore prices, inputs, diverse costs, among other factors. After assuming the restrictions, the conventional study provides for each scenario an economic evaluation considering a certain expected Minimum Acceptable Rate of Return (MARR), together with cash flows, Net Present Value (NPV) and Internal Rate of Return (IRR) [6].

However, the deterministic conventional economic analysis assumes that the imposed restrictions are known with precision and are constant over time, which represents an erroneous simplification, since the estimated of grades, costs, sale prices, among others, are subject to several variations whose totality is impossible to predict with precision. In this context, the risk inherent to the supposition assumes a preponderant role, being necessary to consider it properly through techniques such as the stochastic risk analysis and the sensitivity analysis [7].

The objective of this work is to carry out an economic evaluation study at Mega Mineração, located in Jaboatão dos Guararapes, Metropolitan Region of Recife, State of Pernambuco, Brazil, a company whose economic activity is the extraction and associated processing of a granite for the production of aggregates for construction.

2 METHODOLOGY

The implementation of the Project were performed from 2017 to november 2018, although this economic evaluation were presented in august 2018. Initially, the mineral reserve of the project was calculated based on the topographic survey of the rocky massif. Posteriorly, the scale of probable production and the corresponding lifetime of the mine were defined through a market study, associated with the production capacity of the machinery that would be used in the project, which had already been acquired. According to the definition of the scale of production, it was possible to estimate the annual revenue of the enterprise by means of the average unit value of the mining products sale practiced in the region multiplied by the annual production.

The costs of the project were segmented into CAPEX (Capital Expenditures), which was estimated using the Detailed Estimation Method, and OPEX (Operational Expenditures), estimated using the Similar Project Method, which relates operational costs to other projects of similar magnitude and nature. The general and administrative costs were divided into overhead and variable, in order to simplify the analysis. Taxes, contributions and compensation were categorized as variable costs because their values were dependente of the production. In the project, traditional tax incentives such as depreciation, amortization or exhaustion were not applied, since the company will operate under the fiscal modality of presumed profit and these incentives do not interfere in this situation. On the other hand, a tax incentive existing in the state of Pernambuco denominated the Development Program of Pernambuco (PRODEPE), which directly reduces 75% of the value of the Tax on Circulation of Goods and Transportation and Communication Services (ICMS), was taken account.

The annual inflows and outflows make up the cash flows that, when submitted to a MARR in function of the time, make it possible to obtain the NPV of the project. The MARR used considered the Selic (Special System of Settlement and Custody) of August 2018 (6,5%) multiplied by three in function of the risks of the enterprise, equivalent to 19.5%. The NPV, in turn, is considered the most succinct result of the economic evaluation, which becomes more complete when simultaneously combined with other performance indicators, such as the IRR, the Point of Equilibrium (PE) and the Payback Period (PP). The following relationships between indicators should be considered:

NPV > 0 → The project is profitable;
NPV = 0 → The project is indifferent;
NPV < 0 → The project is not profitable;
IRR > MARR → The project generates profit more than initially expected;
IRR = MARR → The project achieves its profit target;
IRR < MARR → The project does not meet expectations of return.

Because it is a mining enterprise, the result of the calculation of the PE can be obtained in cubic meters of material commercialized. The PP can be calculated by the discounted method, which considers discounted cash flows, bypassing the problem of money value over time by using the MARR as the discount rate.

The risk analysis of the project was carried out using Risk Simulator software version 2017, which uses the Monte Carlo probabilistic method to generate stochastic results for the enterprise variables as definition of the domains and probability functions, using values of maximum, minimum and most likely from the criterion of optimistic,

pessimistic and realistic scenarios. As an auxiliary tool in the analysis, a tornado graph was also produced, which shows the degree of influence of each variable on the result analyzed in the project (in this case the NPV), listing them in descending order of relevance. Were verified 100,000 scenarios that simulated all the selected variables simultaneously, producing a histogram and the cumulative probability distribution of the results for the NPV.
In the second instance, a sensitivity analysis was performed, which indicated, through a percentage graph of explained variation, that only two of the nine variables selected were relevant to the final analysis result (NPV). Then were simulated another 100,000 scenarios considering these variables, resulting in news histogram and distribution of accumulated probability of NPV, thus offering the probabilities that the project will succeed or fail more safely than through the use of conventional tools.

3 RESULTS AND DISCUSSION

3.1 Mineral Reserves

The rocky massif has about 3,183,124.70 m³ of mineral reserve, as estimated from the topographic survey. An average thickness of the overburden layer of 1 (one) meter was considered, resulting in a volume of 199,347.10 m³, which must be removed in the first years of the project. Figure 1 shows the front view of the rocky massif in the north direction.

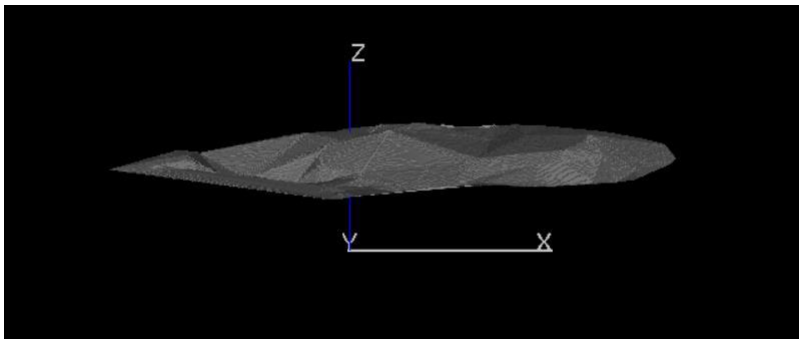

Figure 1. Frontal view of the rocky massif in the north direction [8].

3.2 Gross Revenue

Based on the consumer market situation and the location of the enterprise, which is close to the largest state quarries, the average production rate was estimated at around 25,000 m³/month. It was considered in this estimation that approximately 55% of the material would be delivered to clients of the Northern Zone of Recife and Metropolitan Region through the DDP (Delivered Duty Paid) modality, 25% would be collected by the customers in the quarry through EXW (Ex Works) modality, and the remaining 20% delivered to clients in the Southern Zone and region through the DDP modality. Thus, the average product sales value was obtained through the weighted average between these three types of sales, which present various amounts due to the cost of freight in the DDP modality be incorporated in the tax invoice and the localities are distributed at different distances from the enterprise, as shown in table 1. Due to the fact that 2018 is dedicated to the pre-operational activities, such as the mobilization and implantation of the machines and the construction of the necessary infrastructure, operational activities should start only in the last quarter of this year.

As a result, the estimated gross revenue for 2018 was approximately R$ 5,039,062.50, one quarter of the forecast for the next 14 years, which is approximately R$ 20,156,250.00 per year.

Table 1. Price distribution

SALES MODALITIES	UNIT PRICE (R$/M³)	PERCENTAGE OF SALES (%)
DDP North Zone	75.00	55.00
DDP South Zone	60.00	20.00
EXW	55.00	25.00
AVERAGE UNIT PRICE	**67.00**	

Source: Juvenal [8]

3.3 Capital Expenditure (CAPEX)

The costs of implementation comprise the infrastructure costs, such as earthworks, construction of offices and mechanical garages, installation of crushing equipment, installation of the electrical network, among other improvements. Part of this infrastructure had already been made by the company who owns the mining rights, so costs were lower than usual, totaling the estimated R$ 1,372,000.00.

Costs with the mobilization and acquisition of crushing equipment and mobile machinery were also considered. All equipment used at the beginning of the project was already used in other projects of the group, which is why it was considered that the mobilization of already depreciated equipment represented 40% of the cost of new equipment, totaling R$ 3,354,000.00. The costs of the new equipment were estimated from a database of equipment acquisition of another project of the business group related to Mega Mineração, totaling R$ 8,385,000.00.

The working capital had its ideal amount stipulated in R$ 500,000.00 for the beginning of operations. The costs of studies and projects involved renewal of licenses and reporting to government agencies about the lease of the area on behalf of Mega Mineração for a period of 15 years, since the area was already in mining concession phase and already had an Operating License, totaling approximately R$ 80,000.00, already counting the mining engineer consultant, the project of electrical installations, among other costs. The table 2 summarizes the CAPEX of the project:

Table 2. Total implantation costs

INITIAL INVESTMENTS	COSTS (R$)
Infrastructure	1,372,000.00
Equipments	3,354,000.00
Working Capital	500,000.00
Studies and Projects	80,000.00
TOTAL	**5,306,000.00**

Source: Juvenal [8]

3.4 Operational Expenditure (OPEX)

Considering that operational activities are only to start in the last quarter of 2018, that year's OPEX was about a quarter of the forecast for each of the next 14 years.

3.4.1 Variable costs

The minimum monthly rent of R$ 35,000.00 must be paid to the legal holder of the land and the mining rights, during the 15 years of contract; if the value of 4% of the amount marketed exceeds this value, the lease becomes the percentage of the sale price quoted above. There are also general variable costs that are necessary for the functioning of part of the administration, of the mechanical garage and of the support vehicles of the company, which in this case were considered as R$ 363,960.00 per year.

The unit operations essential for the functioning of the project require frequent replenishment of inputs and wear materials, maintenance and replacement of equipment. The variable costs are described below:

a) Blast plan: was defined from the characteristics of the rock and the desired rate of production. After the calculations necessary for the elaboration of the blast plan, a poder factor of 0.62 kg/m³ was established, being 3.50 R$/kg the unit price of the emulsion explosive. In addition, accessory devices must be used, estimated at 10% of the total blast cost; thus, it is estimated that the annual cost with rock blasting is in the order of R$ 481,687.58.

b) Drilling: will be executed with PW 5000 driller and Atlas Copco XAS 420 air compressor, which shoud drill aproximately 90 meters of rock daily, during 22 days a month. The cost would then be the sum of expenses with fuel, estimated corrective maintenance, replacement of filters, grease and lubricants, as well as the replacement of wear material of the drill string, such as drill bits, steel rods, coupling sleeves and shank adapters. The estimated annual cost for this unit operation is R$ 485,697.70.

c) Loading: must be carried out by 2 (two) excavators and two loaders, who will work 22 days monthly. The costs refer to fuel consumption, replacement of filters, grease and lubricants, as well as corrective maintenance and maintenance of the buckets, bucket teeth and tracks, totaling R$ 1,582,689.36 per year.

d) Haulage: should be executed by 4 (four) Volkswagen 31320 trucks. The operational cost was measured from the sum of the costs with fuel, replacement of filters, greases and lubricants, as well as corrective maintenance and tire replacement, totaling R$ 372,538.08 to be spent annually.

e) Processing: the primary crushing should be performed by the Metso C140 jaw crusher, which costs are related to replacement of jaws, lateral wedges and replacement of lubricating grease. The secondary and tertiary crushing is performed by the Sandvik CS 440 and Metso HP 400 cone crushers, and their operational costs are the replacement of fixed concave mantle, moving mantle and the replacement of lubricating oil and grease. In addition to these, there are also the costs related to the replacement of screens of vibrating sieves, costs with rollers and conveyor belts, besides the electric energy necessary for the operation. Were estimated R$ 1,440,008.52 annually as processing costs. The table 3 summarizes the variable costs described.

Table 3. Variable costs of lease, general and of the unit operations

ITEM	MONTHLY (R$)	ANNUAL (R$)
Lease	55,000.00	660,000.00
General variable costs	30,330.00	363,960.00
Blasting rocks	40,140.63	481,687.58
Drilling	40,474.81	485,697.70
Loading	131,890.78	1,582,689.36
Haulage	31,044.84	372,538.08
Processing	120,000.71	1,440,008.52

TOTAL	**448,881.77**	**5,386,581.24**

Source: Juvenal [8]

Tax costs were also taken account (table 4). The ICMS in Pernambuco affects 18% of the gross revenue of the enterprise, although the incentive of PRODEPE offers the discount of 75% of this tax rate for the activity and location of the company. The Contribution for Social Security Financing (COFINS) and the Social Integration Program/Public Servants' Patrimony Training Program (PIS/PASEP) accounted for 3% and 0.65% of net billing, respectively. Considering that the company is included in the presumed profit regime, the rates of Corporate Income Tax (IRPJ) and Social Contribution on Net Income (CSLL) represent 15% and 9% of this, respectively, in addition to the presumption of 8% and 12%, respectively, which are charged on the tax rates. Lastly, the Financial Compensation for the Exploration of Mineral Resources (CFEM) on aggregate mining equals 1% of net billing [8].

Table 4. Rates, contributions and compensation

ITEM	MONTHLY (R$)	ANNUAL (R$)
IRPJ	20,156.25	241,875.00
ICMS (com o incentivo PRODEPE)	75,585.94	907,031.25
COFINS	50,390.62	604,687.50
PIS/PASEP	10,917.97	131,015.63
CSLL	18,140.62	217,687.50
CFEM	13,750.00	165,000.00
TOTAL	**188,941.41**	**2,267,296.88**

Source: Juvenal [8]

3.4.2 Overhead costs

Considering the professionals who must compose the staff, together with the salaries and the fees inherent to each function, such as insalubrity, dangerousness, nocturnal additional, rate referring to the National Institute of Social Security (INSS), Guarantee Fund for Time of Service (FGTS), vacation and thirteenth salary, in addition to meals and Equipments for Individual Safety (EIS), the annual cost with personnel is equivalent to R$ 1,588,330.92. There is also the necessary costs for the functioning of all the sectors that make up the enterprise, as internet, telephony, security, administrative system, accounting and pro-labore of the partners, that add up to approximately R$ 168,000.00 per year.

The table 5 presents the summary of operational costs, where the "General Annual" column refers to years in which there is no sale and acquisition of new equipment. In the years where the exchange of machinery will occur, this cost will be added to the variable costs for that year. Also included in the years 2022, 2025 and 2027, where there is an exchange of equipment at the end of their useful lives, generating extra revenue and overhead costs in these years.

Table 5. Total operational costs (OPEX)

OPERATIONAL COSTS	GENERAL ANNUAL (R$)	2022 (R$)	2025 (R$)	2027 (R$)
Variable	7,758,053.64	8,598,053.64	10,243,053.64	8,867,553.64
Overhead	1,756,330.92	1,756,330.92	1,756,330.92	1,756,330.92
TOTAL	**9,514,384.56**	**10,354,384.56**	**11,999,384.56**	**10,623,884.56**

Source: Juvenal [8]

Were not considered costs of mine closure and a possible environmental rehabilitation due to the fact that it is not possible to exhaust all the ore in a first lease of 15 years, being it probable that the holder of the mining right rents the enterprise again, for the same group or to another one.

3.5 Conventional Economic Evaluation

The cash flow of year zero results in R$ -3,720,739.72 due to the pre-operational process of installation and structuring of the project. The revenues and costs related to the operation this year occur only in the last quarter, when the mine activity will begin. The balance expected for the common years is positive and amounts to R$ 6,341,041.11. In years 4, 7, and 8 (2022, 2025 and 2027) there will be larger outflows due to equipment exchanges, as the acquisition cost is substantially higher than the residual sales values, resulting in a positive but lower cash flow than the obtained in common years, equivalent to R$ 5,141,041.11, R$ 2,791,041.11 and R$ 4,756,041.11, respectively. In the last year of operation (year 14) there will be a larger entrance than the others, totaling R$ 6,841,041.11, as a result of sales or demobilization of all equipment used. Figure 2 shows a representation of the magnitudes of all the project cash flows.

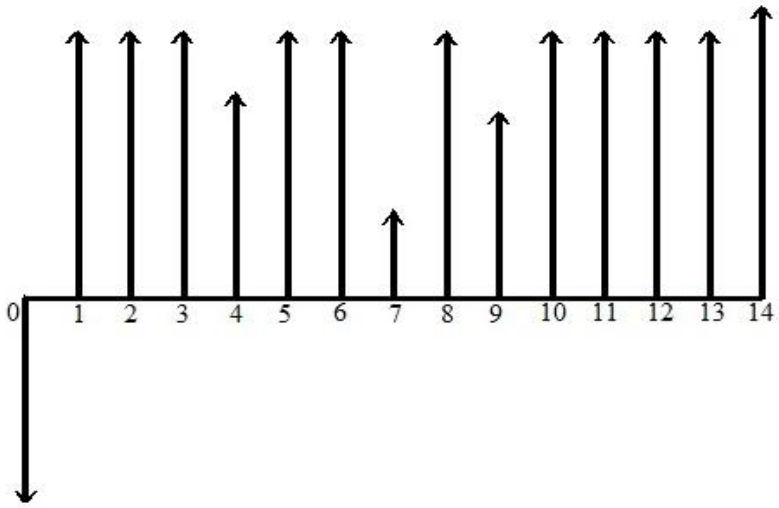

Figure 2. Representation of the cash flows of the enterprise [8].

Depending on cash flow and MARR (19.5%, as mentioned above), the project's NPV is estimated at R$ 24,006.309.20, which would classify it as profitable for the assumed restrictions. The calculated IRR was 169.22%, considerably higher than the MARR used, indicating that the project generates profit above expectations. As the variable costs fluctuate according to the sale and acquisition of new equipment, the PE will vary accordingly each year (table 6), where the "General Annual" column refers to the years in which there will be no machinery replacement. The calculated PP was 20 months, since the beginning of the project, taking into account the pre-operational time; in practice, the payback period was 11 months after the start of the operation.

Table 6. Point of equilibrium of sales at different years of project

YEAR	GENERAL ANNUAL	2022	2025	2027

Point of equilibrium (m³)	42,701.94	45,809.36	53,448.90	46,910.54

Source: Juvenal [8]

Conventional economic evaluation, however, assumes that all the constraints assumed are reality and do not envisage possible variations in the project over time, not considering the risks of the enterprise not reaching the expected values. Therefore, a probabilistic economic evaluation can elucidate what the conventional evaluation did not consider.

3.6 Sensitivity and Risk Analysis

Table 7 lists the variables that were be submitted to the sensitivity and risk analysis, the statistical distributions selected to represent them and also the limits assumed in each distribution.

Table 7. Statistical distributions and probable, minimum and maximum values of each variable submitted to the sensitivity and risk analysis

VARIABLE	STATISTICAL DISTRIBUTION	MINIMUM VALUE	PROBABLE VALUE	MAXIMUM VALUE
Monthly production rate (m³)	PERT	15,000.00	25,000.00	50,000.00
Cost of fuel (R$/L)	Triangular	3.20	3.69	5.20
Electric energy (R$/kWh)	Triangular	0.85	0.92	1.20
Emulsion explosive (R$/Kg)	Triangular	2.90	3.50	4.50
Sale price Northern Zone (R$/m³)	Triangular	60.00	75.00	90.00
Sale price Southern Zone (R$/m³)	Triangular	48.00	60.00	72.00
Sale price EXW (R$/m³)	Triangular	44.00	55.00	66.00
Distribution DDP Northern Zone (%)	Triangular	51	56	61
Distribution EXW (%)	Triangular	20	25	30

Source: Juvenal [8]

The most probable values were obtained in function of those practiced contemporaneously to the execution of this study, while the extreme values of each variable were obtained according to different parameters, as the evaluation of the possibilities offered by the market, a percentage variation for more or for less or, finally, restrictions of the own enterprise.

Figure 3 presents a tornado diagram, which captures the static impacts of each variable and organizes them in a decreasing way in relation to the degree of influence of each one in the enterprise. It is observed that the most relevant variable in the project is the monthly production rate, followed by the sale price in the Delivered Duty Paid (DDP) modality for the Northern Zone.

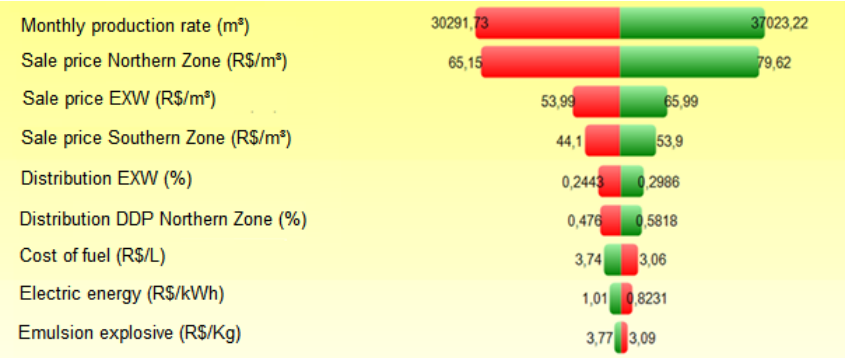

Figure 3. Tornado diagram and results presented by each variable [8].

After the execution of a set of 100,000 Monte Carlo stochastic simulations, the sensitivity analysis was performed. A percentage change chart was generated, which calculates how much of the variation in the final result can be explained by the variations in each of the individual variables in a simulated dynamic domain. In figure 4 it is possible to prove the influence that the production rate exerts on the variation of the final result (NPV), reaching to 84.36% of impact, followed by the influence of the sale price in the modality DDP for the Northern Zone, which holds 11.71% of impact on the variation in the simulated scenarios. Therefore, the other variables put to the test in this second analysis do not present sufficient relevance in the project result, being discarded from the risk analysis performed later.

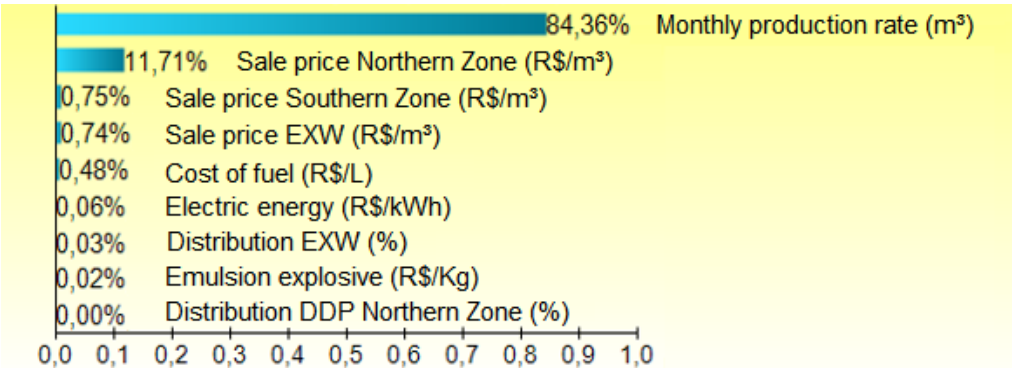

Figure 4. Percentage change chart [8].

From the results of the last 100,000 simulations it was possible to compose the histogram present in figure 5 and conclude the probabilistic economic analysis. In the left histogram the *data* were truncated in NPV equal to zero, where 99.77% of the *data* corresponded to this restriction, which suggests that the project has a high probability of conferring some profit to the investor. In the right histogram the *data* were truncated in the NPV equal to R$ 24,006,309.00, proposed by the conventional economic evaluation, where 49.98% of the *data* correspond to the restriction, indicating that there is less than 50% chance of the project achieve the profit pointed by conventional analysis. The average NPV of R$ 24,198,172.41 was verified, as the median of R$ 24,002,440.01 and the standard deviation of R$ 11,303,567.83.

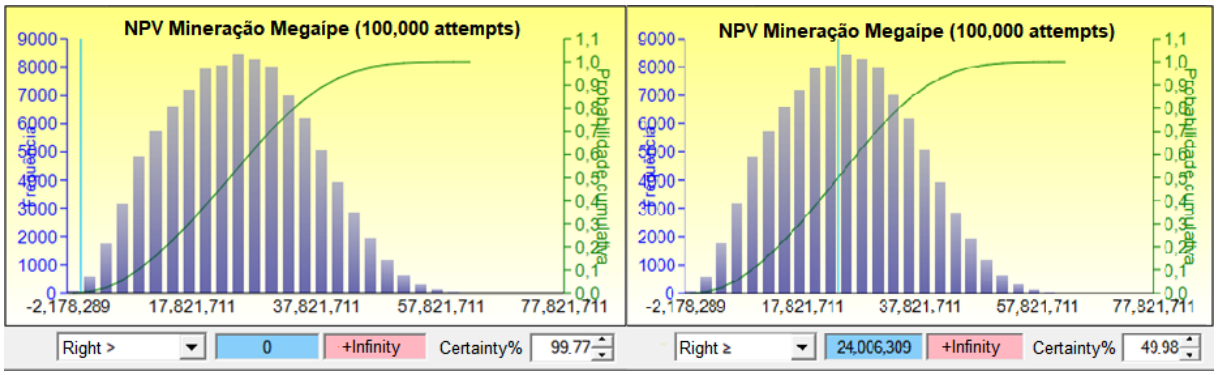

Figure 5. Histogram and distribution of NPV greater than zero and greater than the NPV obtained in the conventional economic evaluation [8].

4 CONCLUSION

The realization of the conventional economic feasibility analysis suggested a NPV value of R$ 24,000,000.00, which indicates the profitability of the enterprise, since the value is greater than zero. The IRR obtained was 169.22%, indicating that the project have a profitability higher than expected because the IRR is substantially larger than the MARR, estimated at 19.5%. However, this methodology does not consider the uncertainties that a long-term project may contain, being necessary the use of tools to provide more consistent and reliable results.

Were selected 9 (nine) variables and assigned statistical distributions to represent them. A tornado diagram was developed to indicate the variables whose changes most influence the NPV result and the first 100,000 simulations were executed. The sensitivity analysis then quantified the predominant influence of two main variables, which were considered in the next 100,000 simulations, when it was possible to perform the risk analysis. It was verified that there is a 99.77% probability of the NPV be greater than zero, that is, the project be profitable, and only 49.98% probability of the NPV be equal to or greater than the R$ 24,006,309.00, value indicated in the conventional analysis.

In addition to reiterating the profitability of the enterprise if the factors considered have adhered to the reality during the initial 15 years, it is evident that the risk and sensitivity analyzes provide more reliable results than the simple conventional economic analysis, since instead of the development of few scenarios it is possible, through the Monte Carlo methodology, to stochastically evaluate hundreds of thousands of scenarios considering statistical distributions for each important variable, thus consisting of an analysis that considers the uncertainties of the project and is practically devoid of bias.

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