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Research Article

Estimating the Regional Development in Gems Mining Areas in Brazil

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ABSTRACT

The activity of extracting gems can be improved if public policies are adopted to expand the production chain in Brazil. In theory, the mining activity could be enhanced by increasing the financial collection of the taxes through mineral extraction aligned with the characteristics of the local economy. The present study uses a decision tree model for classifying the regional development of Brazilian states with gemstone mining activities, based on the regional data on financial compensation for mineral extraction (CFEM), gross domestic product (GDP), Human development index (HDI), environmental impact, and geo-tourism applying decision tree models. CFEM, HDP, HDI, and geo-tourism were continuous variables, and the environmental impact was discretized as 'low,' 'medium,' and 'high.' The results indicate that regional development is not only directly related to revenue from the financial compensation for mineral extraction. The GDP and environmental impact also influence regional development. The variables geo-tourism and HDI did not appear to exert influence on regional development. We infer that the increase in taxes would not directly benefit the local government or community from the results. Further initiatives and appropriate public policies would be necessary for planning the adequate distribution of the received resources from gem mining to improve regional growth and development.

Keywords: HDI, GDP, environmental impact, mining activity, knowledge discovery

INTRODUCTION

The extraction and sale of gemstones have been activities developed since humanity's prehistory. Currently, this activity represents a globalized and complex industry with more than one hundred varieties of gemstones and more than fifty producing countries contributing to the sector's sustainable development, which is little researched. Most researches are still restricted to the gemological characteristics and aspects instead of focusing on the supply chain and sustainability issues around the extraction, processing, and trade of gemstones (Cartier, 2019).

Issues of sustainability, industrialization, and urbanization interrelate, presenting complex patterns and characteristics. Mining area's economic activities deal with non-renewable natural resources that finance urbanization and industrialization. Although mining areas have contributed to world economic development with the supply of minerals, the economic activity also extracts non-renewable resources. Due to the intersection of social, economic, and environmental dimensions, they face obstacles and severe challenges for sustainable development. For the sustainability of mining areas, the supply chain actors need to recognize future shrinkage as a fundamental characteristic, adopt approaches to ecological transformation, such as the circular economy and sustainable business model, develop actions to reduce environmental pollution and social activities (Jiao et al., 2020).

Sustainable development in mining should promote continuous environmental and socio-economic improvement in the mines' activity, operation, and gems commercial phases (Gomes et al., 2014). Such initiatives comply with the UN 2030 Agenda (UN, 2020), reducing inequalities and promoting sustainable development. Sustainable development balances the three fundamental axes economic growth, environmental preservation, and social equity (Dias, 2017). Some aspects will be more relevant than others for specific segments. Thus, new development approaches for community involvement and sustainability should recognize the complex nature of the social systems in which the sector is inserted. These approaches are relevant to the mining segment. Most research nowadays is related to sustainability challenges and the need to keep up with the social, environmental, and economic impacts of extraction, consumption, and commercialization.

Studies related to sustainable development in mining can provide valuable information for the gem sector and respond to the sector's challenges (Cartier, 2019).

The gem mining activity is responsible for several problems caused in the environment and society besides the health and well-being of workers. Therefore, the present study objective is to analyze some social and environmental indicators of gem extraction regions in Brazil that serve as attributes to propose a regional development model related to the financial Compensation for Mineral Extraction (CFEM) recorded in the last ten years. The revenue rates associated with CFEM are paid monthly by the mining company and vary according to the mineral substance. The CFEM return benefit goes to governmental entities at various levels (federal, state, and county). The idea was to observe a relationship between the gem mining's positive and negative impacts on regional development and establish a classification for such progress. It is intended to provide the reader with a view of the relationship between regional development and the CFEM for extracting gems, considering Gross Domestic Product (GDP), Human Development Index (HDI), geo-tourism, and the environmental impacts caused by mineral extraction.

Alternative measures of economic well-being provide a means of assessing the prosperity and sustainability of an economy. However, these variables cannot monetarily estimate economic growth. Allied to GDP, the set of well-being indicators has the potential to provide a heterogeneous macroeconomic assessment of a nation's economic well-being (Cook and Daviosdóttir, 2021).

Information on financial compensation for exploring gems in the mineral extraction scenario concerning regional development in Brazil is not found in the current literature. We focused on classifying regional development into 'high,' 'medium,' and 'low' using continuous correlated development data (HDI, GDP, and CFEM) and qualitative data (geo-tourism and environmental impact). A data mining approach was used to develop the proposed model.

With the development of computers and automation, the storage and retrieval of large volumes of data have increased. Data mining is the procedure of discovering information from a defined set of data. The technique uses mathematical analysis to extract patterns and trends that might exist in data. The classification model is a method of dividing observations into predefined groups according to specific rules or attributes. In particular, decision trees are relatively mature classification algorithms (Eichstaedt et al., 2018; Song et al., 2018). Datasets can be analyzed and utilized to obtain operational rules. In most cases, these rules are clearly understood when transformed into 'if'-'then' rules, which can help generate control strategies. Decision trees use flowchart-like tree structures that allow users to extract helpful information fast and applied in several areas of knowledge (Carvalho et al., 2012; Kara et al., 2018; Zhuang et al., 2018). As a result, data mining and the use of decision tree models have become a valuable tool for identifying and exploring patterns and relationships between a considerable number of interconnected variables (Diez et al., 2006; Namazkhan et al., 2020; Pereira et al., 2013).

The management of the tax revenue of financial compensation for mineral exploration to promote regional development in social, environmental, and economic aspects is not thoroughly studied. The is not an answer for the real influence of the revenue applications on regional development. Therefore, this study aimed to estimate regional development based on the CFEM, GDP, HDI, and geo-tourism applying decision tree models.

BACKGROUND

Sustainable development in mining should promote continuous environmental and socio-economic improvement in the mines' exploration, operation, and closure phases (Gomes et al., 2014). Sustainable development balances the three fundamental axes economic growth, environmental preservation, and social equity (Dias, 2017). Some aspects will be more relevant than others for specific segments. Thus, a new development approach for community involvement and sustainability needs to recognize the complex nature of the social systems in which the sector is inserted. These approaches are relevant to the mining segment.

Mining faces challenges in sustainable development due to the specific characteristics of the activity, associated with several socio-environmental impacts that must be managed if the sector is to develop sustainably. However, this activity plays a fundamental role for society by supplying raw materials for other industries, positively impacting the well-being of the population and economically on the functioning of the global economy (Alves et al., 2020; Gomes et al., 2014). Mining contributes to regional economic growth and poverty reduction at the local and regional levels. It is present in three sectors of the Brazilian economy the primary with mineral research and extraction, the secondary with processing, and the tertiary with the market and trade (Alves et al., 2020).

GDP is the indicator by which the evolution of work and economic growth is evaluated. The non-conformity of the growth of this indicator as a policy objective is revealed by negative implications for the reduction of inequalities, consumption, and responsible production. And yet, in environmental action, targets against climate change, water, and life are linked to the welfare economy's natural capital asset class. There may be indirect negative impacts on the environment caused by the increase in wealth. However, positive effects can be observed in health care and quality education (Cook and Daviosdóttir, 2021). The income obtained from the sale of gemstones in Kenya does not impact the country's GDP due to the low profitability of exporting gemstones in raw form to foreign countries. However, it is believed that adding value to the gem through processing before it is sold and training lapidaries in cutting and polishing techniques will facilitate the way gems can be sold locally or exported. It will cause an increase in revenue collection, thus increasing the sector's contribution to the national GDP.

Furthermore, it can help transform its mineral wealth into economic wealth (Wachira et al., 2019). Alternative measures of economic well-being provide a means of assessing the prosperity and sustainability of an economy. However, they cannot monetarily estimate economic growth. Allied to GDP, the set of well-being indicators has the potential to provide a heterogeneous macroeconomic assessment of a nation's economic well-being (Cook and Daviosdóttir, 2021).

Mining sites have cultural, scientific, geographic, industrial, social, and economic properties that are beneficial to the development of geo-tourism. Using these potentials, through geo-tourism, can contribute as a sustainable rural development strategy to create jobs, eradicate poverty, preserve the environment, and conserve cultural and natural heritage. The contribution of geo-tourism to sustainable development strategies is increasingly recognized worldwide and is seen as a positive factor in the development of mining areas. In summary, mining areas or resources of geological origin that develop geo-tourism based on cultural, aesthetic, historical, educational, and industrial values must be managed on a sustainable basis (Ghazi et al., 2021).

The mining industry has an outstanding role in Brazilian economic and social development. However, sustainability issues have not yet been fully documented and discussed in reports prepared by mining companies worldwide, failing to contribute to policy decisions for sustainable development. Developing a strategy for reducing environmental and social impacts should be an essential step towards laying the foundations for sustainable mining. To achieve sustainability in mining, companies must have a clear concept and a shared vision of sustainability, adopt methods and techniques for sustainable development and create communication strategies between agents and paths to lead the sector towards sustainable development objectives (Alves et al., 2020).

The use and improvement of non-renewable natural resources bring the urban areas into existence and influence economic growth. The depletion of these resources is predictable and causes development to shrink. In an evolutionary view, mining regions can be classified as mining cities in expansion and mining cities in decline (Jiao et al., 2020). The extraction of mineral resources can boost the collection of the mining municipality, allowing a quality public service to be provided to the population and fostering a source of financing for local development with the collection of CFEM. In Brazil, the Financial Compensation for the Exploration of Mineral Resources (CFEM) is a right that the union, the states, the federal district, and the municipalities have on mineral resources in the country territory (Brazil, 1988). It is incumbent upon the National Mining Agency (AMN), an autarchy linked to the Ministry of Mines and Energy, to set standards and exercise control over the CFEM tax, to share revenues. Nowadays, tax share goes to Federal District and municipalities where the mineral is extracted (60%). Also, to Federal District and states where the mineral is extracted (15%); to union (10%), and Federal District and counties (15%) when affected by mining activity and production that does not occur in their territories (Brasil, 2017).

The revenue rates related to CFEM are paid monthly and vary according to the mineral substance. Rocks (including sands, gravels, gravel, and other substances intended for civil construction, ornamental stones, water minerals, and hot springs, 1%), gold (1.5%), diamond and other mineral substances (2%), and iron (up to 3.5%, that may suffer a reduction in the rate due to its content). Up to the limit of 4%, the taxation is focused on the sale, consumption, exports, mineral goods acquired in public action, and extraction under the mining prospecting regime (Brasil, 2017). CFEM rates are levied on the net billing amount, deducting taxes and expenses incurred during commercialization. If the product is consumed, transformed, or used by the miner himself, the value of CFEM is based on the sum of the direct and indirect expenses incurred up to the moment of using the mineral product (ANM, 2004). Brasil (2017) states that stakeouts and waste from gem-active mining areas are considered mineral assets to collect CFEM. Whenever used in other production chains, such products will reduce the rate of CFEM up to 50%.

Research Questions, Methods, and Decision tree Model

The two research questions in the present study are:

- Does the financial compensation for mineral extraction (CFEM) help improve the regional development of gem mining in Brazil? and
- Is there a relationship between the positive (GDP and HDI) and negative variables (that result in environmental impact) of gem mining and the regional development in Brazil?

METHODS

We analyzed the Financial Compensation for Mineral Exploration (CFEM) in four states of the Brazilian federation (Piauí-PI, Paraíba-PB, Rio Grande do Sul-RS, and Minas Gerais-MG). Each state has opal, tourmaline, amethyst, and emerald mining operation (**Figure 1**). Data were organized to help understand the discrete and continuous quantitative and qualitative variables to estimate regional development. These variables were necessary for constructing the final table that served as input for the data mining process.

Description of the Variables

Gems mining corresponds to an economic and industrial activity that involves researching, exploring, extracting, and processing raw material present in the subsoil. In Brazil, such activity is essential for the region's socio-economic development where it takes place. However, mining activity is responsible for several problems caused in the environment and society, such as the health and well-being of workers (Serrano et al., 2016). As a counterpart to extracting natural resources, mining companies return to union the CFEM, which must necessarily be committed to projects to improve health, education, culture, and the Municipality infrastructure that holds the mining activity.

The indicators present in **Table 1** were considered to build up the social dimension, with geo-tourism being classified as Yes (Y) if the state encourages geo-tourism and No (N) if the state does not encourage geo-tourism.

The economic dimension evaluated the percentage of financial compensation for mineral exploration of the gems related to the other gemstones explored in each state (**Table 2**).

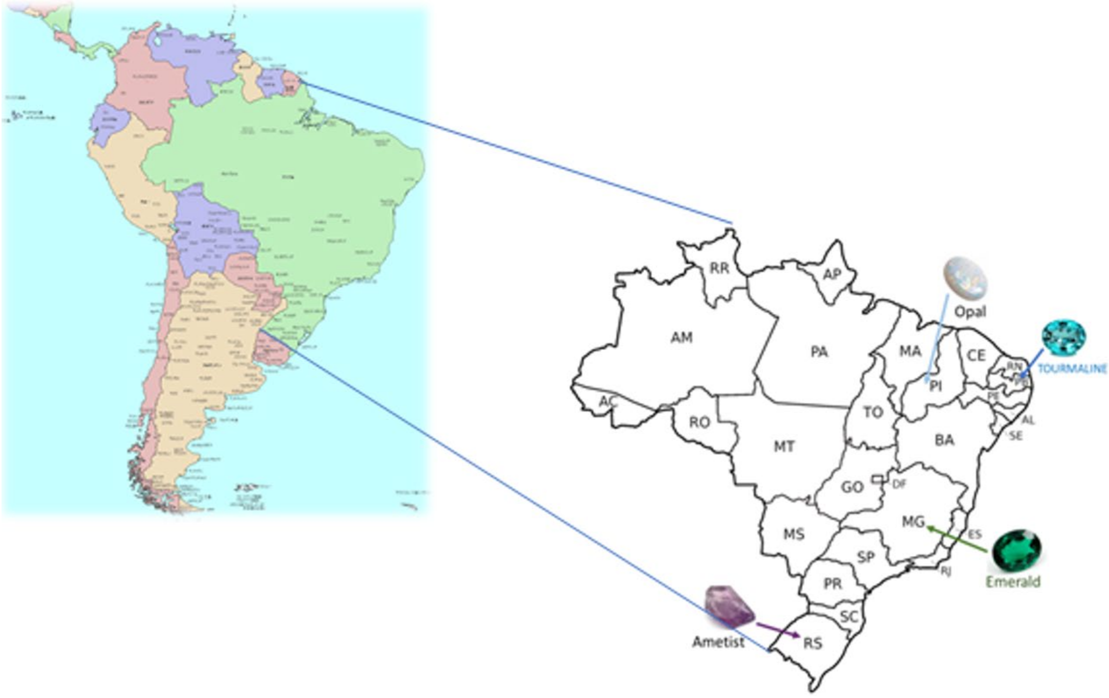

Figure 1. Map of Brazil with the indication of the gems mining sites

Table 1. Estimate values of variables used to assess social impact in the studied regions

Year	State	Geo-tourism	HDI	GDP (10^{-4} Reals)	Year	State	Geo-tourism	HDI	GDP (10^{-4} Reals)
2010	PI	Y	0.646	2227	2010	RS	Y	0.746	24125
2011	PI	Y	0.644	2594	2011	RS	Y	0.752	26506
2012	PI	Y	0.664	2864	2012	RS	Y	0.757	28759
2013	PI	Y	0.671	3128	2013	RS	Y	0.763	33229
2014	PI	Y	0.678	3772	2014	RS	Y	0.779	35782
2015	PI	Y	NA	3915	2015	RS	Y	NA	38199
2016	PI	Y	0.690	4142	2016	RS	Y	0.783	40879
2017	PI	Y	0.697	4536	2017	RS	Y	0.787	42315
2018	PI	Y	NA	4536	2018	RS	Y	NA	42315
2019	PI	Y	NA	4536	2019	RS	Y	NA	42315
2010	PB	N	0.658	3352	2010	MG	Y	0.731	35112
2011	PB	N	0.681	3711	2011	MG	Y	0.745	40012
2012	PB	N	0.682	4249	2012	MG	Y	0.754	44228
2013	PB	N	0.692	4638	2013	MG	Y	0.762	48800
2014	PB	N	0.701	5294	2014	MG	Y	0.769	51663
2015	PB	N	NA	5614	2015	MG	Y	NA	51933
2016	PB	N	0.709	5910	2016	MG	Y	0.781	54481
2017	PB	N	0.722	6239	2017	MG	Y	0.787	57620
2018	PB	N	NA	6239	2018	MG	Y	NA	57620
2019	PB	N	NA	6239	2019	MG	Y	NA	57620

Source: Adapted from PNUD (2017), Liccardo and Chodur (2009), and Carvalho (2015). PI= Piaui State, PB= Paraíba State, RS= Rio Grande do Sul State, and MG= Minas Gerais State. NA= data not available.

Table 2. CFEM estimate (%) used to assess the economic impact in the studied gemstones extraction

Year	CFEM Opal (%)	CFEM Tourmaline (%)	CFEM Amethyst (%)	CFEM Emerald (%)
2010	0.051	0.00	0.026	0.002
2011	0.045	0.00	0.029	0.002
2012	0.015	0.00	0.060	0.002
2013	0.010	0.00	0.006	0.002
2014	0.000	0.00	0.010	0.003
2015	0.005	0.00	0.046	0.006
2016	0.003	0.00	1.284	0.008
2017	0.000	0.00	0.513	0.005
2018	0.038	0.00	3.542	0.034
2019	0.327	0.00	3.784	0.022

Source: Adapted from DNPM (2020). CFEM= Financial Compensation for the Exploration of Mineral Resources

Table 3. Classification description adopted for environmental impact estimation

Classification	Description
Low	There is low vegetation removal, little erosion, waste treatment, low water contamination, and slight surface excavation.
Medium	There is medium environmental impact, low use of waste treatment, and medium surface excavation
High	There is high vegetation removal, high environmental impact, high river pollution, and high excavation.

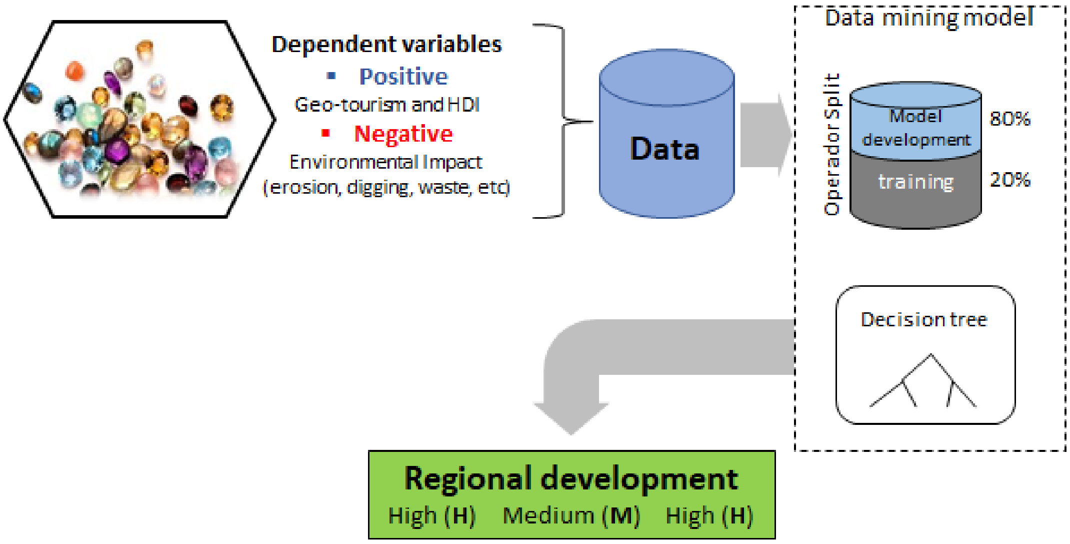

Figure 2. Schematic visualization of the data mining process with the input variables, the model processing, and the regional development output

The model's discretized variable of the environmental dimension was estimated by the erosion, excavation, and tailings removal. As a result of this approach, the environmental impact was classified as 'low,' 'medium,' and 'high' with some established characteristics (**Table 3**).

Decision Tree Model

The data set was built using the continuous and discrete variables and applied to develop a decision tree model (design with the concept of 'if-then' rules). The Rapidminer® Studio, open-source software based on Java version 9.2 (RapidMiner, Inc. Boston, Massachusetts, USA), was used to process the data. The database was inserted considering the continuous and discrete variables to obtain the degree of regional development (low, medium, and high). The decision tree is a classification function that assigns items in a collection to categories or classes (variables). The objective of the classification is to accurately predict the target class for each case in the data. In this particular case, **Tables 1-3** were used as attributes.

The output function (target) was 'regional development,' with the alternatives of 'low,' medium, 'and 'high.' The operators used were 'retrieved data,' 'split data,' and 'decision tree.' In the present study, 80% of the dataset was used to train the algorithm and 20% to develop the decision tree model (Wu and Yang, 2021). The subsequent set of items in the training set is recognized by the attributes classified concerning various samples in a more precise approach (Lavrac, 1999). Accuracy was calculated using Eq. 1.

$$Accuracy\ (\%) = \left(\frac{TP + TN}{TP + FP + FN + TN}\right) \times 100 \qquad (1)$$

where TP=true positive, TN=true negative, FP=false positive, FN=false negative.

The concept of κ was first established by Cohen (1960). The statistical coefficient κ is related to the inter-rater reliability applied to evaluate two evaluators' agreement, meaning simply the proportion of agreement after agreement due to chance is removed from being considered. The calculation of κ may be performed according to Eq. 2.

$$\kappa\ = \big(PR(a) - PR(e)\big) \div (1 -\ PR(e)) \qquad (2)$$

where Pr(a) signifies the observed agreement, and Pr(e) denotes the chance agreement.

In the present study, we assumed that the classification was appropriate when $\kappa \geqslant 0.60$. The schematic of the process is shown in **Figure 2**.

RESULTS AND DISCUSSION

The decision tree model indicates that regional development is not only directly related to revenue from the financial compensation for mineral extraction. The GDP and environmental impact also influence regional development. The variables geo-tourism and HDI did not appear to exert influence on regional development (**Figure 3**). We found a model with high accuracy (87.5%) and κ =0.71.

Figure 3 represents the decision tree model of estimating regional development based on the financial compensation for the use of mineral resources (CFEM), GDP, and the environmental impact. According to the model, the input variables geo-tourism and HDI did not seem to play an essential role in regional development. From this result, it was

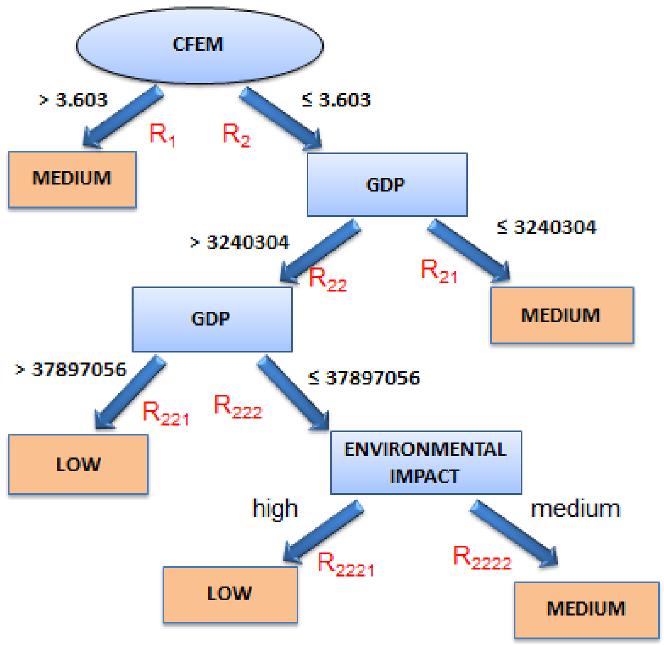

Figure 3. Decision tree model classifying the regional development as a function of the Financial Compensation for the Exploration of Mineral Resources (CFEM) by the gem mining, the GDP, and the environmental impact. The CFEM values are shown in ^10⁴ Reals

Table 4. Description of the decision tree branches found applying data mining and the 'if-then' rules

Branch	Data representativity (%)	Results
R_1	28	**If** CFEM > 3.603, **then** regional development is classified as medium.
R_2	72	**If** CFEM ≤ 3.603, **then** to classify the regional development, one needs to analyze GDP.
R_{21}	6	**If** GDP ≤ 3240304, **then** regional development is classified as medium.
R_{22}	66	**If** GDP> 3240304, **then** GDP needs to be analyzed again.
R_{221}	25	**If** GDP > 3789056, **then** regional development is low
R_{222}	41	**If** GDP ≤ 3789056, **then** the environmental impact needs to be analyzed.
R_{2221}	22	**If** the environmental impact is high, **then** the regional development is classified as low.
R_{2222}	19	**If** the environmental impact is medium, **then** the regional development is classified as medium.

possible to extract the following rules by the branches, up to four levels of decision (**Table 4**; R_1, R_2, R_{21}, R_{22}, R_{221}, R_{222}, R_{2221}, and R_{2222}).

The present study results indicate that the direct relationship between financial compensation for mineral extraction and regional development was not evident, with a given representativity (72%) in the social or environmental aspects. Regarding regional development and environmental impact, it can be seen that with a given representativity (22%), there is an inverse relationship observed in the decision tree branch R_{2221}. We can observe that this correlation does not exist between regional development and GDP, requiring assessing the environmental impact to classify regional development.

These results agree with previous findings of Silva et al. (2017), showing that the large levy of royalties from oil or mining does not directly impact social or environmental development. Nevertheless, Enriquez (2007) also suggests no direct correlation between mining activity in the state and changes in the condition of poverty and income concentration, similar to those findings in this research. Like the current study, Frare et al. (2020) found a decision tree model to promote sustainability in small municipalities. The authors' input variables were based on nature and social well-being, sustainable public administration, cultural management, sustainability education, and urban planning and accessibility. At the same time, the author's model classifies the option of fostering improvement in sustainability by planning the local development and the population quality of life. In the present study, if the environmental impact is 'high,' the regional development is 'low,' even considering different levels of GDP. This might indicate the importance of reducing the environmental impact to promote regional advancement in gemstone mining areas.

Milanez and Oliveria (2013) studying the opal mining cluster in Brazil, found that despite some adequate policies that have prompted innovation with positive effects on the performance of artisanal mining, decision-makers should plan to make this cluster more sustainable. In this aspect, policymakers would have to include other regional economic activities such as geo-tourism to open up more job fronts. However, our results did not indicate geo-tourism as a variable that would affect mining areas' regional development.

Mining is one of the oldest human activities that benefit humankind as it represents revenue and helps to improve economic activities. A key aspect of sustainable development is rational extraction focusing on limiting extraction (Dubinski, 2013). The concept of sustainable development in mining is controversial since the activity is linked to non-renewable natural resources. Thus, one of the main challenges for sustainable development is applying sustainability to positively contribute to the environmental, social, and economic regional aspects (Alves et al., 2020). The relationship between technology and socio-environmental performance in mining is crucial in increasing the efficiency of the process, reducing production costs, and decreasing pollution and depletion of natural resources (Arango-Aramburo et al., 2017). However, such initiative is only possible with governmental investment in education. The funding for such a project could come from the CFEM aid if properly administered. The way the allocation is structured now, the most regional development reached is 'medium,' for grant values higher than $3.603^{\wedge}10^4$ Reals (**Figure 3**). All other alternatives point out 'medium' or 'low' regional development. Further studies need to be done to subsidize solutions to improve the gem mining activities and help regional development.

CONCLUSION

We presented a decision tree model to estimate the regional development of some Brazilian states with gem extraction considering discrete and continuous variables related to regional development. As a result of this analysis, it can be shown that regional development is not directly related to the financial compensation for gem extraction, a taxation concept used to help regional development compensation for the removal of minerals and increase in mining waste.

When the GDP is 'low,' and the environmental impact is 'high,' the regional development is 'low.' When the GDP is 'low,' and the environmental impact is 'medium,' the regional development is 'medium.' The decision tree model showed the need to estimate the environmental impact categories in gem mining to classify the regional development where the mining takes place.

Further studies should consider other variables as indicators, which in some way can better represent mining working conditions and the mitigation of environmental impacts. However, the variables involved are not simple to assess. Finally, it seems necessary to re-discuss the financial compensation for mineral extraction and the licensing procedure for mineral activities in Brazil, seeking better integration between sustainable regional development and gem mining activity.

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Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

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