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Contributions to improve sustainability conditions in gemstone-benefiting companies

Contribuições para melhoria das condições de sustentabilidade em empresas beneficiadoras de gemas

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ABSTRACT

The gemstones and jewels production chain have been an important source of income and job creation in several regions of Brazil. However, sometimes, its activities haven't been developed in an environmentally correct and sustainable context. In this sense, this work seeks to investigate indicators, to propose a framework of indicators to evaluate and monitor the sustainability conditions of companies that process gemstones. Therefore, a proposal was prepared considering the specificities of the sector, containing 10 indicators and 24 variables distributed in the environmental, economic, social, and technological dimensions. The proposal was verified empirically with a company, a case study, located in Teutônia/RS, which presents the main characteristics of the companies belonging to the sector. The use of the framework of indicators provided information on the company's sustainability conditions, identifying positive aspects and also those that need to be improved to assist in the search for a more sustainable management of activities. On the other hand, the results achieved present information that can serve as a reference for comparison with other companies in the sector, as well as assist in the decision-making process in search of more sustainable conditions.

Keywords: indicators; sustainability; gemstone benefiting companies.

RESUMO

A cadeia produtiva de gemas e joias tem sido uma importante fonte de divisas e de geração de empregos em diversas regiões do Brasil. No entanto, por vezes, suas atividades não têm sido desenvolvidas em um contexto ambientalmente correto e sustentável. Nesse sentido, este trabalho busca investigar indicadores, com a finalidade de propor um quadro de indicadores para avaliar e monitorar as condições de sustentabilidade das empresas beneficiadoras de gemas. Para tanto, foi elaborada uma proposta considerando as especificidades do setor, contendo 10 indicadores e 24 variáveis distribuídos nas dimensões ambiental, econômica, social e tecnológica. A proposta foi verificada empiricamente junto a uma empresa: um estudo de caso, localizada em Teutônia/RS, que apresenta as principais características das empresas pertencentes ao setor. A utilização do quadro de indicadores forneceu informações sobre as condições de sustentabilidade da empresa, identificando aspectos positivos e também os que necessitam ser melhorados para auxiliar na busca de uma gestão mais sustentável das atividades. Por outro lado, os resultados alcançados apresentam informações que podem servir de referência para fins de comparação com outras empresas do setor, assim como auxiliar no processo de tomada de decisão em busca de condições mais sustentáveis.

Palavras-chave: indicadores; sustentabilidade; empresas beneficiadoras de gemas.

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Introduction

In many countries, especially developing ones, mining is a sector with a significant share of the economy (Ranängen and Lindman, 2017), as a source of income, employment, and inputs to other industries (Azapagic, 2004; UN, 2016). Among the different minerals that can be extracted from nature, there is the mining of precious stones, including diamonds, emeralds, and garnets (Hentschel et al., 2003) and given these characteristics, the factors that interfere in mining activities depend on where they are carried out (Ranängen and Lindman, 2017).

Despite its economic importance, there are only few studies that discuss the economic, social, and environmental aspects of gem production (Oliveira and Ali, 2011) and it becomes relevant due to the non-renewable nature of most mineral resources and its ability to generate a series of environmental and social impacts that affect regions negatively (Falck and Spangenberg, 2014; Lodhia and Martin, 2014). This way, the maintenance of the activity is necessary, but must be carried out in a more sustainable context so that it is less harmful to the environment in which it is inserted.

In this context, Brazil stands out for the variety of gems found in its territory, since it has one of the largest gemological provinces in the world. Estimates indicate that the country is responsible for one third of the world's production of gems, except for the production of diamonds, rubies, and sapphires (Barreto and Bittar, 2010).

In the state of Rio Grande do Sul, where this work was developed, the main product in terms of exported value refers to precious (except diamond) or semi-precious stones (COMEX STAT, 2021). According to Barreto and Bittar (2010), the state is the largest producer of uncut colored gemstones in Brazil and one of the main producers of agate and amethyst. Activities of extraction, manufacture of artifacts, and processing of gems (polishing, hammering, dyeing, cutting, among others) are generally carried out by small companies, which need to make improvements in the production processes and investments in technologies, seeking improvements in the flow of materials, in the reduction of losses, and in the management of the environmental liabilities resulting from the activity, in order to achieve more sustainable conditions. According to Brasil (2021), companies in the segment had an average of 10 formal workers in 2019, demonstrating that most activities were carried out in small companies (a reality that has not changed much in the last decade, since it maintained the average number of workers of 2009).

These companies face problems and conditions similar to other small-scale mining activities, such as the use of rudimentary methods, manual and low-level technology (Massaro and Treije, 2018), poor qualification of the workforce and informality (Zvarivadza and Nhleko, 2018), inefficiency for adding value, low level of productivity, limited use of mechanization, lack of investments, extraction of minerals in unauthorized deposits, among others (Hentschel et al., 2003; Oliveira and Ali, 2011).

To soften this situation, companies belonging to the gem processing sector need to adopt different actions that help to face these difficulties, like the use of sustainability indicators, which serve to monitor the development of their activities and, thus, contribute to the achievement of more sustainable conditions.

In literature, it is possible to observe several initiatives to propose general indicators for industries (Azapagic and Perdan, 2000), manufactures (Lee and Lee, 2014), and micro and small companies (MSC) (Chen et al., 2014). However, due to the specificities of different sectors and organizations, the use of standardized methodologies is not always efficient. According to Chen et al. (2014), there are still few tools easily applicable for MSC to assess sustainability. Therefore, the development of initiatives of proposals of indicators for these companies in specific sectors (Chen et al., 2012; Joung et al., 2013) has been observed. In addition, Ranängen and Lindman (2017) argue that, although mining sustainability is on the global agenda, the criteria to be prioritized depend on the regions where it is developed.

Based on the above, the scope of this study is defined as the investigation of indicators, with the purpose of proposing a framework to assess and monitor the sustainability conditions of gemstone processing companies, taking into account their characteristics.

Sustainability indicators

In the literature, there are different functions and definitions for sustainability indicators, such as:

- providing information to decision makers on the global level of sustainability of a system and contributing to the elaboration of strategies in pursuit of this objective (UN, 2007);
- providing information to facilitate the understanding and communication of complex systems (Falck and Spangenberg, 2014);
- making a problem visible (Dahl, 2012);
- assisting in the selection of the best alternative and contributing to the identification of the causes of unsustainability (Callens and Tyteca, 1999);
- allowing the elaboration of more sustainable development strategies (Azapagic and Perdan, 2000), among others.

To Joung et al. (2013), a set of indicators, through the combination of environmental, economic and social indicators, guarantee a holistic view of sustainability, as they assess reality from a larger scale than that of individual indicators. They can also be used to compare the situation at a given moment and the desired situation (where it is intended to go), showing the extent to which sustainability objectives are being met (Ragas et al., 1995).

Unlike other indicators, sustainability indicators are differentiated by the obligation to measure the capacity of a system to adapt to changes over a period of time and continue to operate, that is, sustainability indicators must contribute so that a system maintains its state or function over time, and it is therefore essential to consider antecedents that also explain the system's resilience (Milman and Short, 2008).

Resilience is generally understood as the adaptive capacity of a system (Folke, 2006), being initially considered only from an environmental-ecological perspective (Xu et al., 2015). However, considering that impacts are caused by productive activities and human interactions, it is also essential to assess resilience in the social dimensions, considering their ability to access critical resources (Langridge et al., 2006), including water, land, finance, and human skills, and economics, associated with the ability to withstand market shocks and allocate resources efficiently (Perrings, 2006).

Initiatives for building sustainability indicators applied to companies were led by the Global Reporting Initiative (GRI), which seeks to motivate organizations to adopt more sustainable practices through the use of sustainability reports and, thus, contribute to sustainable development (GRI, 2013). Other proposals for evaluating the performance of companies in reaching these goals are proposed by the Organization for Economic Co-Operation and Development (OECD, 2003) and by the World Business Council for Sustainable Development (Verfaillie and Bidwell, 2000). Chen et al. (2014) also highlight that there are a variety of methods and tools available in the literature that contribute to the development of indicators at different levels and dimensions.

However, although these proposed sustainability reports are developed for organizations in general, regardless of their size, sector or location, they do not provide a universal framework of indicators that can be used indiscriminately by everyone (Segnestam, 2002), nor they indicate sufficient conditions for sustainable development, as there are no reference values (Callens and Tyteca, 1999), especially for MSC due to the type and amount of information requested.

For this reason, it is possible to observe the development of several initiatives to propose indicators to assess sustainability conditions of companies of this size, such as: Ragas et al. (1995) present a proposal for the construction of sustainability indicators applied to production systems, seeking to measure all forms of environmental pressure during the life cycle of a product; Callens and Tyteca (1999) developed a methodology of indicators that allow the assessment of the participation of companies in sustainable development; Azapagic and Perdan (2000) propose a general framework for sustainable development indicators for the industry; Veleva and Ellenbecker (2001) present a structure and methodology for the use of sustainable production indicators as a tool to promote greater awareness, measurement, and preparation of sustainability reports; Krajnc and Glavic (2003) presented a set of sustainable production indicators to assess a company's level of sustainability and help define more sustainable options for the future; Azapagic (2004) proposed a comprehensive set of indicators that are specifically relevant and adapted for the mining and minerals industry; Joung et al. (2013) reviewed a set of indicators available to the public and provided a categorization of quantifiable and clearly related indicators to manufacturing; Chen et al. (2014) presented a holistic sustainability assessment tool for the manufacture of MSC, among others.

Even so, small companies, especially manufacturing companies, have been challenged to choose which are the best indicators to evaluate their processes and products, and to interpret these indicators in their decision-making (Chen et al., 2012; Joung et al., 2013). And this has been the reality faced by companies in the gem processing sector, as there is a lack of management of the usefulness of the many proposals for indicators and the specificities of the sector. Therefore, this work aims to investigate indicators, with the purpose of proposing a framework to evaluate and monitor the sustainability conditions of gem benefiting companies, given their importance for many countries, as is the case of Brazil.

Next, the methodological procedures used to prepare proposals for sustainability indicators applied to the industries that benefit from gems are stated.

Methodological procedures

This section presents the considerations that guided the development of the proposed sustainability indicators aimed at companies in the gem processing sector and their empirical verification in a case study company. Considering this objective, the study is classified as exploratory, quantitative, and qualitative.

The methodology for defining the proposed indicators was guided based on the steps described by Joung et al. (2013). Thus, sustainability objectives were defined, indicators were selected, reference values and measurement procedures were defined and, afterward, the data analysis and report elaboration showing the results for the company's case study were carried out, which can serve as a comparison for other companies in the segment.

Specificities and key issues for the development of activities of the gem processing sector in a sustainable context were also considered. These issues were identified through the analysis of previous studies on the sector (Hentschel et al., 2003; IBGM, 2005; Oliveira and Ali, 2011) and the monitoring and analysis of the production process directly in the manufacturing environment.

During three years, the researchers made weekly visits and follow-ups to the company's case study in order to understand the functioning of its activities, the changes in the economic scenario, and the solution of the problems they faced. In this company, an inventory of the inputs and outputs of the process was also carried out, based on the analysis of the life cycle of the materials (Callister and Rethwisch, 2013), in order to identify critical points in terms of resource consumption and waste generation, effluents, and emissions. However, it is noteworthy that the assessment was restricted to the impacts generated during the production process and the possibility of recycling materials in the process itself, that is, the phases of mining and extraction of gems, oil, and other materials in the phases were not considered prior to their arrival at gem processing companies, as well as in the later stages of waste disposal and recycling.

This step also contributed to the definition of values that need to be minimized (such as consumption of resources and environmental responsibility), as well as those that must be maximized (recovery and recycling of materials), in order to achieve efficiency in the activity (Callens and Tyteca, 1999). This occurs because, initially, for the development of sustainability metrics, the main aspects that need to be managed and included in the proposal need to be identified (Tanzil and Beloff, 2006). In addition, an interview was conducted with the company's case study managers, based on a structured questionnaire, which aimed to identify the conditions necessary to achieve the sector's sustainability conditions.

The selection of indicators was carried out taking into consideration the observations made from the process inventory and issues highlighted by the managers, as well as the literature review and analysis of initiatives related to the construction of sustainability indicators and guidelines discussed in the second section of this article, for industries and manufactures, especially in MSC, or companies associated with the mining sector.

Literature review was carried out based on works available especially in the SciELO, ScienceDirect (Elsevier), and Google Scholar databases. For this purpose, keywords were used as an initial search reference (such as: Sustainability indicators, Manufacturing, Industry, Mining Sector, Sustainability indicators, Manufacturing, Industry, Mining Sector), and from them, other relevant works referred to were consulted, following the snowball methodology, with the objective of expanding the scope of research. Given the systemic nature of the theme, in this study, Boolean operators were not used, as there were few works published directly in the area under study and, as new related terms appeared, the searches were expanded. This review was not exhaustive, since not all the works found in the search were analyzed, although it sought to identify the main proposals for indicators applied to companies, in order to support the achievement of the objective of this work.

In this context, for the assessment of the sustainability conditions of gem processing companies, a proposal for indicators was developed considering four dimensions of sustainability: environmental, economic, social, and technological. This selection took into account the concept of the Sustainability Tripod (Triple Bottom Line) (environmental, economic, and social dimensions), proposed by Elkington (1998), widely recommended in the literature, as well as the need to incorporate technologies to meet sustainability goals, as suggested by Joung et al. (2013). The purpose of this dimension is to assess the ability of companies to introduce technological advances. According to Hentschel et al. (2003), among the main difficulties of artisanal or small-scale mining activities are the limited use of mechanization and the lack of investment capital. In addition, according to Oliveira and Ali (2011), the low level of technology used in the sector is an obstacle to increasing productivity and income.

In addition, it was decided to consider two sustainability attributes in each dimension: productivity and resilience. The first attribute is directly associated with the concept of sustainable production, since, to obtain this quality, it is necessary to improve the productivity of processes (Porter and Van Der Linde; 1995) through a more efficient use of resources and minimizing the generation of waste, considering that some resources used by the sector are finite (gems and oil). Meanwhile, resilience is associated with the ability of systems to absorb disturbances, to reorganize themselves during the process of changes and recovery, and to maintain their function, structure, and identity over time (Costanza and Daly, 1992; Folke, 2006; Xu et al., 2015). Other attributes were not inserted in order not to make the tool more complex and, at the same time, it was understood that if companies were efficient in achieving these two attributes, they would also indirectly achieve other sustainability attributes, such as stability, diversity, security, among others.

Thus, based on the analyzed sustainability indicator proposals, in the reality of companies that benefit gems, and on the dimensions and attributes of sustainability to be considered, sustainability indicators and variables that would compose each indicator were selected and defined with the help of the managers of the company's case study (Table 1).

The proposed indicators were empirically verified with a case study company, through the analysis of documents, including production management documents, monitoring of technical reports, and waste management plans. The project was chosen for convenience and is in the interior of the state of Rio Grande do Sul (Brazil); it can be classified as small, given the number of employees and annual turnover. In addition, the company operates using a typical gem processing process, as occurs in other companies in the sector and in face of difficulties similar to those previously reported.

And, considering that each indicator was measured in different units of measurement, in order to be able to group the results and calculate a sustainability index, it was necessary to normalize the results, transforming them into the same unit, as highlighted by Nardo et al. (2005). Therefore, it was chosen to assign weights from 1 to 3 for each variable, in order to show the worst situation (grade 1), an intermediate situation (grade 2), and the best situation to achieve more sustainable conditions (grade 3). To define the parameters related to each weight, studies of the mining sector were consulted (Azapagic, 2004; ANA, 2006; Norgate and Haque, 2012; Strezov et al., 2013; Lodhia and Martin, 2014; Thammaraksa et al., 2017; Chen et al., 2018). Other parameters were defined with the help of the company's case study managers, who have a deeper understanding of the sector's reality (practitioners) and the context in which the gem processing activities are carried out. The parameters were defined to indicate a bad, intermediate or ideal result for the processing of gems considering the principles of sustainability. Table 1 shows the weights and parameters by sustainability variables and indicators.

After measuring and normalizing the variables, the indicators were aggregated by arithmetic mean. For example, Equation 1 shows how the 'resource consumption' indicator was calculated.

Table 1 – Weights, parameters, variables, indicators, attributes, dimensions of sustainability.

Weights, parameters, variables, indicators, attributes, dimensions of sustainability	Dimension	Attribute	Indicator	Variable	Parameters	Weight
	Environmental (25%)	Productivity (50%)	Consumption of resources (33.3%)	Water consumption	Up to 50 m^3 / ton From 50 to 100 m^3 / ton More than 100 m^3 / ton	3 2 1
				Energy consumption	More than 60% renewable 30 to 60% renewable Less than 30% renewable	3 2 1
				Fuel consumption	Up to 60 l / ton From 60 to 120 l / ton More than 120 l / ton	3 2 1
			Material recovery/ recycling (33.3%)	Oil recycling	More than 60% 30 to 60% Less than 30%	3 2 1
				Gem recovery	More than 60% 30 to 60% Less than 30%	3 2 1
			Environmental liability (33.3%)	Total waste generation (sludge)	Less than 30% 30 to 60% More than 60%	3 2 1
				Production of defective parts	Less than 1% Between 1% and 5% More than 5%	3 2 1
				Generation of waste without treatment	Less than 30% 30 to 60% More than 60%	3 2 1
		Resilience (50%)	Environmental management (100%)	Adoption of environmental management system	Yes - No	3 2 1
				Adoption of CSR / Sustainability practices	Yes - No	3 2 1
				Irregularity notifications	No - Yes	3 2 1
	Economic (25%)	Productivity (50%)	Management and diversification of the activity (50%)	Savings from material recovery or recycling of material	More than 5% Between 1% and 5% Less than 1%	3 2 1
				Waste disposal costs	Less than 1% Between 1 and 5% More than 5%	3 2 1
				Making investments	Yes - No	3 2 1
				Commercialization channels	5 or more channels Between 3 to 4 channels Up to 2 channels	3 2 1
		Resilience (50%)	Adaptability to changes (50%)	Development of new products	Yes - No	3 2 1
				New product revenue	More than 5% Between 1 and 5% Less than 1%	3 2 1
	Continue …					
	Social (25%)	Productivity (50%)	Working conditions (50%)	Qualification and training of employees	Yes - No	3 2 1
				Incidence of accidents at work	Yes - No	3 2 1
		Resilience (50%)	Worker satisfaction (50%)	Turnover	Up to 10% Between 10 and 25% More than 25%	3 2 1
				Benefits offered by the company	Yes - No	3 2 1
	Technological (25%)	Productivity (50%)	Technological Investments (100%)	Introduction of technological innovations	Yes - No	3 2 1
				Adoption of Cleaner Production practices	Yes - No	3 2 1
		Resilience (50%)	Innovation capacity (100%)	Participation in R & D	Yes - No	3 2 1

$$I1 = \frac{V1.1 + V1.2 + V1.3}{3} \quad (1)$$

The higher these results for the indicators (closer to 3), the better the company's performance in pursuit of the objective; and the lower the values (closer to 1), the greater the distance to be traveled by the company to achieve sustainability conditions.

Indicators were aggregated by attributes, and attributes by dimension, considering the same previous criteria. Equations 2, 3, 4, and 5 show how indicators were aggregated by dimension.

$$D_{Environmental} = \frac{A_{1+}A_2}{2} = \frac{\left(\frac{I_1 + I_2 + I_3}{3}\right) + \left(\frac{I_4}{1}\right)}{2} \quad (2)$$

$$D_{Economic} = \frac{A_{1+}A_2}{2} = \frac{\left(\frac{I_5}{1}\right) + \left(\frac{I_6}{1}\right)}{2} \quad (3)$$

$$D_{Social} = \frac{A_{1+}A_2}{2} = \frac{\left(\frac{I_7}{1}\right) + \left(\frac{I_8}{1}\right)}{2} \quad (4)$$

$$D_{Technological} = \frac{A_{1+}A_2}{2} = \frac{\left(\frac{I_9}{1}\right) + \left(\frac{I_{10}}{1}\right)}{2} \quad (5)$$

Finally, it was possible to calculate the level of sustainability that indicates the current condition of the company that collaborates in this study in relation to the search for sustainability. This index was obtained from the aggregation of the evaluations by dimension, with each dimension receiving the same weight in the calculation of the index (Equation 6).

$$S_{index} = \frac{D_{environmental+}D_{economic} + D_{social} + D_{technological}}{4} \quad (6)$$

The results found in the company's case study in relation to the proposed sustainability indicators are described in the following sections.

Results and Discussion

This section first describes, briefly, the characteristics of the gem processing process. Next, the table of sustainability indicators suggested for the companies in the sector is presented, and afterward the results of the assessment of the sustainability conditions of the case study company are demonstrated. Finally, some general discussions are presented.

Gem benefiting process

The typical gem processing process consists of several stages (cutting, turning, sanding, polishing, finishing, among others), some of which are marked by manual processes, while others are characterized by semi-automatic or automatic processes, varying according to the type of gem and the final product to be obtained, with the average time required for the development of this process being approximately 30 to 45 days.

In these stages, different types of resources are used, especially natural gems and marine diesel oil, and different types of solid and liquid residues are generated, as shown in the inventory of inputs and outputs of the process (Figure 1).

Given this scenario, companies in the sector need to find alternatives to minimize the use of inputs and the generation of waste, with the aim of making the activity more efficient and sustainable. Therefore, the use of a framework of sustainability indicators can be useful.

Proposed sustainability indicators

The indicator table for gem benefiting companies was developed according to the sustainability objectives (Joung et al., 2013) and the characteristics of the activity and is based on four dimensions (environmental, economic, social, and technological) and two sustainability attributes (productivity and resilience), consisting of 10 indicators (quantitative and qualitative) and 24 variables (Figure 2).

The environmental dimension seeks to portray the impact that the productive activity can cause on the environment, as well as to identify whether production has been developed in an environmentally correct context. It consists of four indicators and 11 variables. The indicators associated with the productivity attribute (consumption of natural resources, the recovery and recycling of materials, and the environmental liability resulting from the beneficiation process) are traditional indicators, considered in evaluations of the life cycle of a product, as they seek to measure the main resources used and the environmental impacts resulting from the production process (Lee and Lee, 2014). For parameter purposes, the best (most sustainable) situation will be one in which the consumption of materials and the environmental liability are as low as possible per quantity of gems processed; at the same time that the reuse of materials is maximized. The resilience of companies in this dimension is expressed by the indicator called environmental management, which can be guaranteed with the adoption of environmental management systems and sustainable practices. In addition, companies must comply with rules and legislation to mitigate their environmental impact and thus avoid notifications of irregularities. Although this last issue seems simple to meet, in practice it is not due to the informality of the sector, the inadequate working conditions, or the acquisition of gems from unauthorized deposits (Azapagic and Perdan, 2000; Hentschel et al., 2003; Azapagic, 2004).

The economic dimension is formed by two indicators and six variables. The first indicator, associated with the productivity attribute, aims to analyze the management and diversification of the activity, through the analysis of the economy resulting from the reduction and reuse of materials, the costs associated with the disposal of waste, the investment, and the dependence on relation to the commercialization channels. In this case, companies would achieve more sustainable conditions if the values associated with the first and third variables

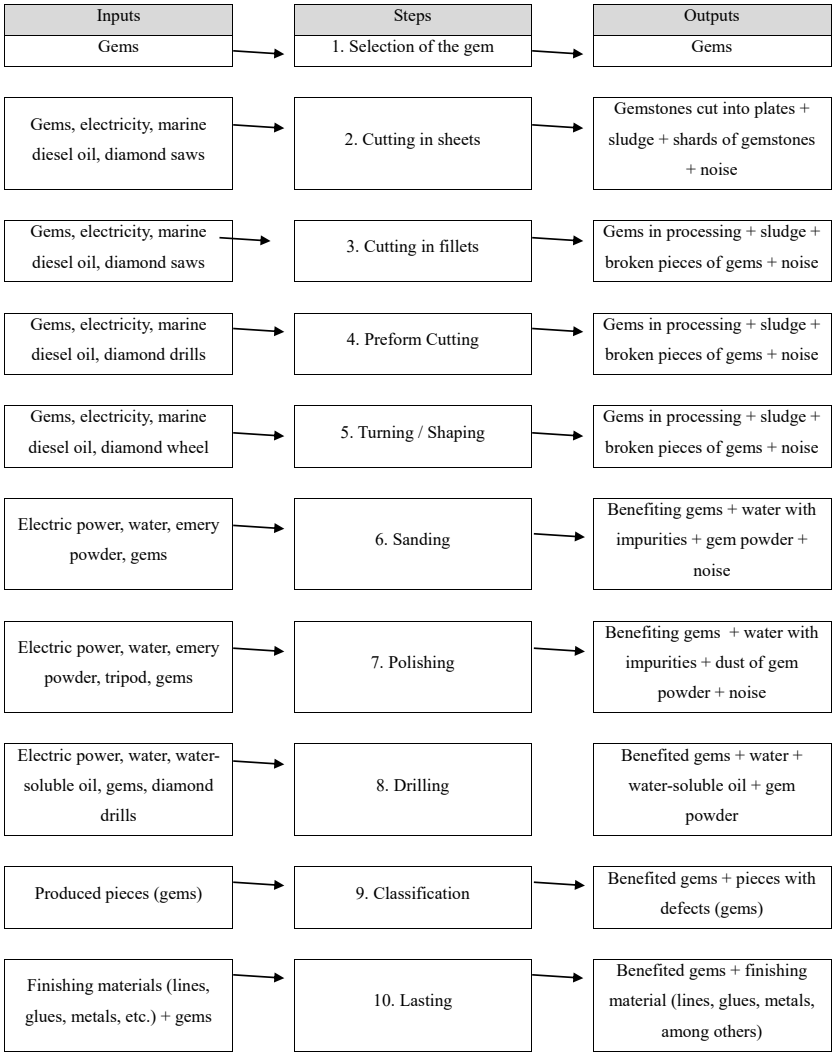

Figure 1 – Inventory of inputs and outputs of the gemstone benefiting process.

are maximized and the values for the second and fourth variables have been minimized. The second indicator of this dimension, linked to the resilience attribute, the company's ability to adapt to changes in the market, assesses the capacity to develop new products and the revenue associated with them in relation to the total invoiced by the company. As the gem processing market produces products considered superfluous, not essential for the survival of human beings, it is very susceptible to market changes; therefore, companies must always be in search of development of new attractions for consumers, *i.e.*, the best performance will be obtained when these values are maximized. In addition, no indicator is included to measure the actual billing, present in other proposals, as it was considered vital that the company needs to make a profit in order to continue its activities.

Social dimension consists of two indicators and six variables. The productivity attribute is expressed by the working conditions indicator, formed by two variables that demonstrate the accomplishment of qualifications and training of employees and the number of incidents of work accidents, as it is expected that no company represents work risks (Joung et al., 2013). The indicator associated with the resilience attribute seeks to measure the satisfaction of workers through the analysis of the turnover index and the benefits offered by companies as a means of encouraging employees to remain in the activity, in addition to those required by the legislation in the country. Indicators that could measure the company's impact on the local community were not included in the proposal, as suggested by Azapagic and Perdan (2000) and Joung et al. (2013), given the difficulties faced by small compa-

nies, they will hardly be able to develop specific actions directed to the population in their surroundings, and their positive impact on society will be through the generation of jobs, income, and the respect for the environment and legislation.

The technological dimension is composed of two indicators and three variables. The productivity attribute is expressed by the technological investment indicator, which aims to inform whether companies are introducing technological innovations and Cleaner Production practices. The innovation capacity indicator, associated with the resilience attribute, seeks to identify whether companies participate in research and development projects or in sectoral projects, whose objective is to develop actions that benefit the sector. The performance of the indicators of this dimension are fundamental to guarantee the increase of the efficiency of the productive processes, therefore, the better the performance of these indicators, the more sustainable the systems tend to be (Oliveira and Ali, 2011; Joung et al., 2013).

In addition, although the indicators have been classified by sustainability dimension, their improvement tends to provide positive results over the other dimensions as well, as highlighted by Tanzil and Beloff (2006), causing an overflow effect. In other words, the better performance of environmental indicators guarantees a reduction in the costs of production and treatment of waste in order to contribute to economic performance as well. Thus, the introduction of investment in technologies can contribute, for example, to a more efficient use of resources, bringing positive impacts on the environmental, economic, and social dimensions.

Assessment of the sustainability conditions case study company

In 2014, the case study company benefited an average of four tons of gems per month; the production consisted of jewelry and decorative items, which were destined for both the domestic and foreign markets.

In environmental terms, associated with the productivity attribute, it was found that the company used a significant amount of non-renewable materials (in particular gems and marine diesel oil) and reused a reduced volume of materials (approximately 45% of the oil and 8% of the total volume of gem waste). As a result, due to the low percentage of finished product, the benefiting process generated a significant volume of sludge, which, due to its characteristics, is classified by the Brazilian legislation as hazardous and cannot be disposed anywhere in the environment, which represents a high environmental liability.

In the period analyzed, the company generated approximately 20.4 tons of sludge, representing 42.5% of the total volume of processed gems. Although this sludge was treated through the washing process, which partially recovered the oil, and which was reused in the production process, approximately 80% of the total volume was stored in barrels, while waiting for a more efficient treatment, so as not to be sent to an industrial landfill.

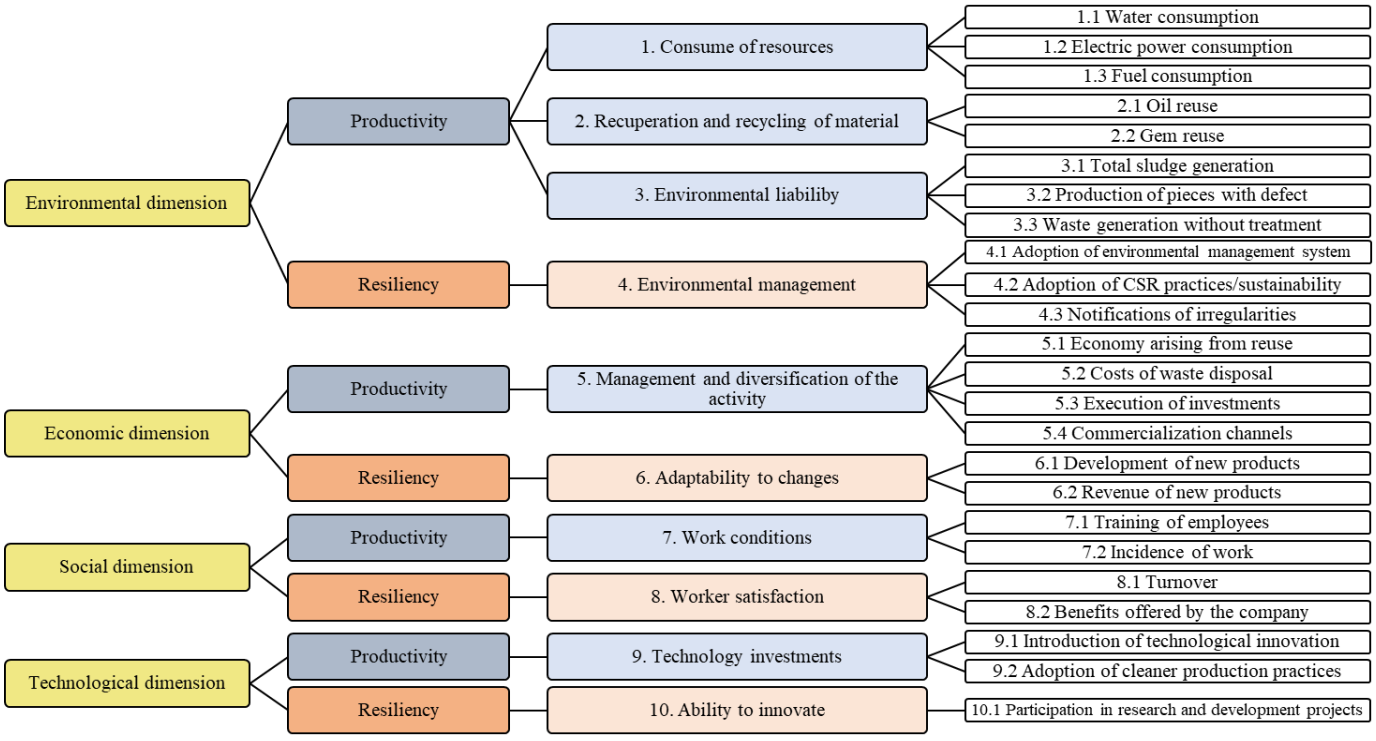

Figure 2. Proposed indicators for assessing sustainability conditions in companies in the gem processing sector, classified by attributes and dimensions.

In addition, the environmental management indicator, related to the resilience attribute, demonstrated that the company, despite adopting practices that contribute to sustainability, such as the use of techniques aimed at Cleaner Production (reuse of waste) and development of a new product from the residue formed by gem powder, and not having committed irregularities, it did not adopt any environmental management system, due to the reduced availability of resources and manpower, as highlighted in other studies (Hentschel et al., 2003; Azapagic, 2004; IBGM, 2005).

The economic dimension is formed by two indicators that seek to measure the company's ability to manage and diversify its activity (productivity attribute), and to adapt to changes that may occur in the market (resilience attribute). Regarding the performance of these indicators, it was observed that although the company has made investments in the productive sector, contributing to the improvement of efficiency, there was no cost with waste disposal, as it accumulated the waste in vats in the company's yard while developing techniques for its treatment, having used several channels for the commercialization of its products (wholesale, retail, website, at fairs, among others). However, it saved only 2% by reusing materials, as well as it had a small increase in revenue due to the development of new products with reuse of materials, showing that it still needs to adopt measures to improve its performance in search of sustainability, especially associated to waste reuse and increased billing with the commercialization of new products. On the other hand, it is observed that if the company improves the environmental indicators it will also be contributing to the results of the economic dimension, demonstrating the interrelationship between them.

The social dimension was assessed by the indicators: working conditions (productivity attribute) and employee satisfaction (resilience attribute). As the analyzed company is characterized as small, its involvement with the community occurs through the generation of jobs and income, while not polluting the environment, respecting the legislation applied to the sector. The indicators associated with this dimension performed well, as the company provided training and qualifications to its employees and there was no incidence of work accidents, although the company needs to adopt measures to reduce employee turnover and offer benefits to its employees, contributing for their better quality of life.

On the other hand, the company's performance in view of the technological dimension was adequate to achieve the conditions of sustainability, as suggested by the literature (Oliveira and Ali, 2011; Joung et al., 2013), the company has sought to introduce technological innovations in the productive process, through automatic faceting machine, and cleaner production practices, aimed at reusing materials and making 5S, in addition to participating in research and development projects, developed by a university located in the region and representative agencies of the sector in the state, which aim to make better use of resources and reduce the generation of waste resulting from productive activity (Figure 3).

These indicators were also aggregated by attribute so that it was possible to obtain an index by dimension (Figure 4) and a general index of sustainability.

The environmental sustainability index for the collaborating company was 2.25. The indicator that most contributed to this result was the consumption of materials (2.67), since, when compared to other industries, the company uses a reduced volume of water per volume benefited and, in terms of energy, it only consumes electricity from renewable sources. The performance of the environmental passive indicator (2.33) was also satisfactory, as well as the environmental management indicator of the activity (2.33), since the company did not allocate any waste to industrial landfills during data collection and has adopted practices favorable to sustainability and received no notification of irregularity. On the other hand, the indicator that contributed less to this indicator was the reuse and recycling of materials (1.50).

The economic sustainability index obtained a result equal to 2.38. In this dimension, the activity management and diversification indicator (2.38) performed well, since the company had no expenses with the disposal of waste, made investments in the productive sector and used several marketing channels to place its products. The adaptability to changes indicator, however, needs to be improved (2.00), as, despite the company developing new products to meet customer demand and seeking to reuse materials, the revenue from this development is still insignificant.

The sustainability index for the social dimension was 2.25. While the working conditions indicator got the best score, since the company trains employees and no accidents at work were recorded, the employee satisfaction indicator underperformed, provided the turnover rate is not only low, but it does not offer any benefits to its employees.

The technological dimension of sustainability index was 3.00, that is, it presented the best score of all indicators. This result is due to the investments in innovation that the company has made, as well as

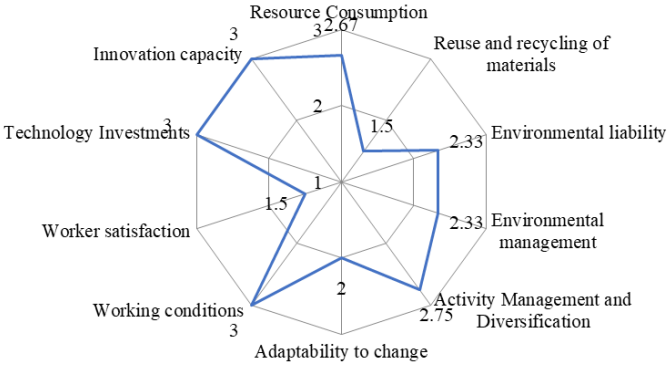

Figure 3 – Diagram of sustainability by indicator.

the adoption of Cleaner Production practices aiming at increasing productive efficiency and its involvement with research and development projects and sectorial entities.

And, finally, the company's sustainability index of 2.47 was also measured, demonstrating that the company has managed to achieve a satisfactory performance in the search for sustainability conditions. However, it is recommended that the company seeks to develop actions to improve, mainly, the performance of the variables associated with the environmental and social dimensions. In addition, considering the relationships between the dimensions of sustainability, it is evident that, by improving the performance of one dimension, one will also be contributing to the performance of other dimensions.

This was an initial exercise for the assessment of sustainability conditions in gemstone benefiting companies; the indicators have been validated from a case study and generalizations cannot be made from the results found.

Discussions

Along the development of this work, three aspects become evident. First, identifying evidence about the production process. Although the activities developed by the mining sector are important for the economy, the literature presents few studies associated with the gem processing sector. The inventory of inputs and outputs of the gem processing process, presents detailed information on the main critical points. It highlights the aspects that need to be minimized during the process of gem processing and those that must be maximized to achieve efficiency in the perspective of sustainability, as highlighted by Callens and Tyteca (1999). In particular, it was identified that benefiting companies need to minimize the use of inputs (especially gems and diesel oil) and the generation of waste and maximize the reuse of gems and improve their productivity to become more efficient and sustainable.

The second contribution of the study is related to the proposition of the framework of sustainability indicators, composed of indicators linked to the environmental, economic, social, and technological dimensions, and based on the attributes of productivity and resilience for the development of activities in this sector. The proposal is advantageous for companies because it followed the recommendation of works widely recognized in the literature, it considered the reality in which they are inserted and counted on the participation of practitioners involved in the activity (company managers of the case study), thus contributing with small companies that have limited resources in terms of time and personnel (Dahl, 2012; Falck and Spangenberg, 2014) and have more difficulties in using more generic indicators for all types of industry, as for example proposed by GRI (2013).

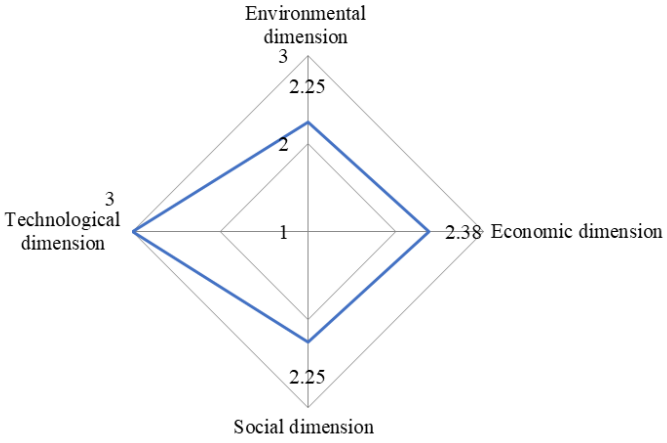

Figure 4 – Assessment of sustainability conditions by dimension.

However, despite the advantages associated with the adoption of the proposal, it is worth noting that it may have limitations, since this is a simplified framework of indicators that will not be able to measure everything that happens in the company, according to a characteristic identified by Bossel (1999), neither guarantees its sustainability (Dahl, 2012). This is an initial proposal that can be adjusted according to the emergence of new needs and demands in the sector. For this reason, the list of indicators cannot be considered exhaustive and rigid (fixed).

Also, another obstacle that companies in the sector may face in adopting the proposal is associated with the collection of information and monitoring of the indicators due to difficulties with the workforce, which is generally unskilled, with a low level of education and is often reduced (the same person has several functions within the company) (Hentschel et al., 2003), it can also present high turnover, directly related to the regional economic performance (employees easily change jobs when other sectors pay better). The third contribution of the study is associated with its applicability. The empirical verification of the proposal in the case study company presents an overview (by indicator, dimension, and general sustainability index) objectively evidencing the main difficulties faced. Thus, the practical implication of this study is that company managers can use the results as an instrument for evaluating and monitoring their activities in search of a more sustainable context. The results can also be used to disclosure reports to stakeholders, so as to communicate the actions developed by the company.

Furthermore, the proposal can also be used by companies that are part of the sector, for the purpose of comparison among them; as well as it can be useful for carrying out a general evaluation of the sector. Consequently, this information could be used as a subsidy of governmental or non-governmental organizations for the development of policies aimed at the sector that presents numerous difficulties (Hentschel et al., 2003).

Conclusions

This study provided information about the production process of gemstone benefiting; an important economic activity for many countries, especially in Brazil, and proposed a framework of sustainability indicators to assess and monitor the sustainability conditions of small companies. The main advantage of the proposal is that it was developed taking into consideration the reality and the

specificities of the sector and it had the involvement of stakeholders for the selection of variables, in addition to being applied in a case study company. Thus, the indicators express the main limitations that this segment faces and expose opportunities for improvements to be implemented along the process to achieve better sustainability conditions.

It is suggested as a future work to conduct a survey to confirm the parameters. Obtaining these results will contribute to the review of the reference parameters for the measured variables and, if necessary, to make changes to the initial proposal. The proposed indicators applied to other companies in the sector will allow a comparison among them and a general assessment of the sector. Monitoring these indicators will also contribute to verifying whether the companies are managing to develop their activities under more sustainable conditions and whether the proposed tool favors or not the improvement of the productive process.

Contribution of authors:

Sindelar, F.C.W.: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing — original draft. Barden, J.E.: Conceptualization, Methodology, Formal analysis, Supervision. Stulp, S.: Conceptualization, Methodology, Formal analysis, Supervision.

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