Universidad de Lima

Facultad de Ingeniería y Arquitectura

Carrera de Ingeniería Industrial

PROSPECTIVE STRATEGIES TO IMPROVE THE ENVIRONMENTAL SUSTAINABILITY OF THE COPPER MINING INDUSTRY IN PERU

Tesis para optar el Título Profesional de Ingeniero Industrial

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Lima – Perú

Noviembre de 2022

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Abstract

The prospective is a tool that allows to generate future scenarios; however, there are some limitations since there are few prospective studies for the copper mining sector. This sector is very important for Peru since it contributes 10% to the national GDP and represents 65.7% of all exports. However, the processing of copper generates large environmental impacts, such as: gaseous emissions, particulate matter, dumping and hazardous solid waste. On the other hand, this is a strategic prospective study with a mixed approach, to determine future sustainable copper mining scenarios and contribute to the improvement of sustainability. In the methodology, the MICMAC was used to determine the key variables, the Mactor and Smic-Prob-Expert software to play the game between actors and define future scenarios respectively. As a consequence, it is suggested the improvement of the fusion process of the mining companies using clean technologies and energies to minimize gas and particulate matter emissions. Finally, 64 scenarios have been generated, of which it was considered that scenario 1 is the best sustainable scenario for the copper mining industry, since it has the highest probability of occurrence with 0.481 and it is where all the hypotheses are fulfilled.

Keywords
Mining, Copper, Environmental Aspects, Sustainability, Prospective strategies.

1. Introduction

This article analyzes the strategic prospective to improve the sustainability of the copper mining industry in Peru. This sector is very important for the economic sustainability of Perú since it has one of the longest mining histories in South America (De Echave 2020). The stellar place of this activity in the country's productive matrix was validated by performing the Porter analysis and the PESTLE of the macro context in which the Peruvian copper mining industry is located. Its most relevant characteristics are the current requirement of environmental protocols and quality certifications, the low cost of production and the dependence on the economic model. However, this industry faces multiple problems such as the environmental impact of mining projects and poor management of production processes. Covre et al. (2021) explain that incorrect disposal of copper mining wastes can threaten the ecosystem and human health due to high levels of potentially toxic elements released into the environment. Essentially, we can distinguish two dimensions in this issue: environmental and social. The environmental dimension mainly covers air pollution from gas emissions, particulate matter and the generation of tailings resulting from mining activities, as indicated by Ávalos (2018), a large part of the mining sector has fines for non-compliance with the Maximum Permissible Limits (MPL). The Sankey diagram of Ávalos (2021) shows that the main outputs in the copper production process are solid waste gas and emissions such as sulfur dioxide and particulate matter (Figure 1).

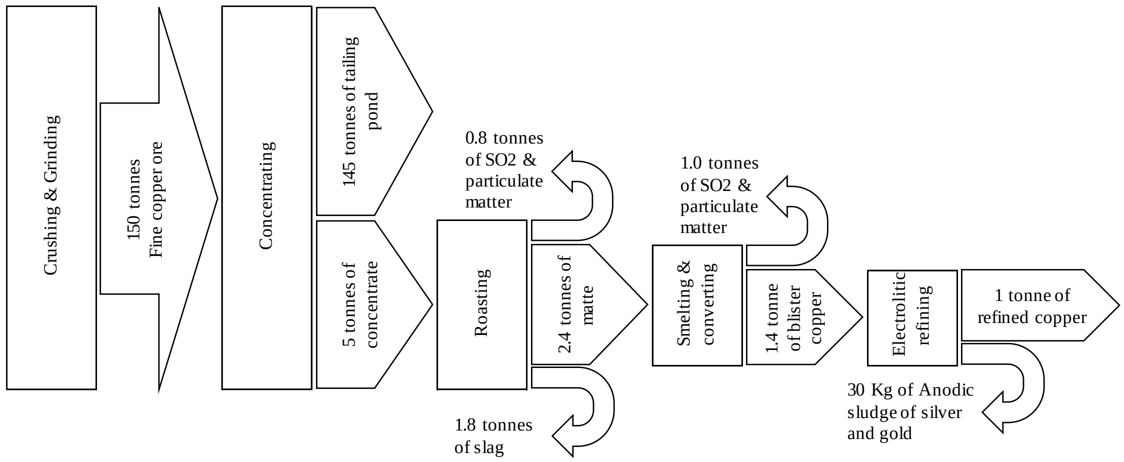

Figure 1. Sankey diagram for the copper industry

Then a Life Cycle Analysis was carried out in which the generating outputs with the greatest environmental impact were identified at each stage of the copper production process. When these impacts are characterized by a Characterization diagram, it is revealed that each of the outputs generates a different environmental impact, resulting in the damage of the soil, water and air. To determine which solid waste concentrated has the greatest amount generated, the Pareto chart was used; this showed that the tailings represented more than 80% significant, so it was necessary to analyze the causes of such quantity. For this, the Ishikawa diagram was used; this reveals that the main causes are the following: the control of variables (RPM, residence time, number of reactants), copper deposits with low copper grade, less than 2% copper concentration in raw materials and operational control of mineral consumption and reactants. The same procedure was carried out to determine which gaseous emissions were the most relevant and their main generation causes. The Pareto chart reveals that sulfur dioxide accounts for more than 80% significant, and according to the Ishikawa diagram, this occurs due to the following causes: the production orientation of the organizational culture, the copper fusion beds concentrate high levels of sulfur (more than 20%), clean technologies are not incorporated into roasting processes and conversion and EMS is not included in strategic planning.

On the other hand, the social issue of Peruvian mining encompasses all those social problems that derive from air pollution from copper mining operations. According to a report published this year, 65% of active social conflicts in Perú correspond to the socio-environmental type and 64% of these are related to mining activities (Defensoría del Pueblo 2021). Saenz (2018) argues that mining projects with a complex-unstable context require considerable effort and a longer process to obtain a Social License to Operate (SLO). Due to this, the research question that this work proposes is: Is it possible that through the strategic prospective of the copper mining industry in Peru, favorable future scenarios will be identified regarding the improvement of environmental sustainability?

The main objective of this article is to identify possible future favorable long-term scenarios regarding the improvement of the environmental sustainability of the copper mining industry through strategic prospective using the Smic-Prob-Expert software. Likewise, within the specific objectives, the first will consist of making a diagnosis of the current situation of the Peruvian mining industry. The second will be, identifying and validating the variables that are related to improving the sustainability in the Peruvian copper mining. The third will be in charge of carrying out a structural analysis. Finally, the fourth objective will focus on the validation of these findings.

2. Literature Review

The Strategic prospective is a vital tool for fulfilling our multiple and complex mandates and expressing the field and scope of our expectations and desires (Godet and Durance 2011). Precisely, Godet and Durance (2007) explain that the prospective, whatever it may be, constitutes an anticipation (preactive and proactive) to illuminate the present actions with the light of the possible and desirable futures. The prospective provides the basis for a long-term reflection on the system under study that gives a multidimensional and multiscale vision of it (Trujillo and Verdegay 2020).
Peru has had a long mining tradition that has extended into the 21st century, being a source of foreign exchange generation that has contributed to maintaining the macroeconomic balance of the nation (Nugra et al. 2021). The minerals produced in Peru are in great demand in today's world market, whose development is based on production

and industry. The United States, China, Switzerland, Japan, Canada and the European Union are the main applicants (MINEM 2021). Likewise, Valenta et al. (2019) specifically point out that copper supply supports global economic growth and human development. Copper is one of the most valuable and prevalent metals used in the industry (Al-Saydeh et al. 2017). In this way, Andújar et al. (2021) use the strategic prospective approach to identify variables that characterize the Peruvian copper mining sector as an investment attractiveness, socio-environmental conflicts, and political management. However, the mining and mineral processing industries have been the main focus of research in many countries due to their growing sustainability concerns affecting global warming and climate change (Farjana et al. 2019). Specifically, Jiang et al. (2021) mentions that copper mine tailings are causing great environmental concern today due to their high content of heavy metals. In the same way, Fuentes et al. (2021) acknowledge that increases in copper production created additional pressure on the environment, resulting in the need for an accurate evaluation of the environmental sustainability of copper extraction. That is why, to objectively identify and characterize the environmental impacts of the copper production process, one of the tools used was the Life Cycle Analysis, in which Farjana et al. (2019) comment that among the various environmental impact assessment tools that are widely used to identify sustainability indicators, Life Cycle Assessment (LCA) is a well-justified approach among practitioners and researchers. In the same way, Asif and Chen (2015) suggest that the implementation of appropriate environmental management tools such as life cycle assessment (LCA), cleaner production technologies (CPT), are important since, they lead to improved environmental performances and allow that the mines focus on the next stage of sustainability. Consequently, Hilson and Murk (2000) comment that, to contribute to sustainable development, a mine must minimize environmental impacts throughout its life cycle, from exploration, through extraction and refining, to reclamation. Therefore, the management focus should be on prevention rather than cure to avoid environmental problems (Fresner 1998).

The purpose of this research is to identify the best future scenario for copper mining in order to achieve the improvement of sustainability in this sector. Mathiyazhagan et al. (2013) point out that as customers become more environmentally conscious and governments establish stricter environmental regulations, industries must reduce the environmental impact of their supply chain. And thus, in the mining industry, the incorporation of sustainability management practices aims to minimize the environmental impacts inherent to this activity (Gomes et al. 2014). Finally, because almost all forms of business pollution are manifestations of economic loss; for example, resources used inefficiently, waste of energy, or valuable raw materials discarded; it is important to state that economic competitiveness can improve from the better environmental performance, because business pollution derives from the unproductive use of resources (Porter 2017).

In summary, due to the high levels of pollution caused by copper mining, it is essential that mining companies prevent and minimize their environmental impacts throughout the life cycle of their production processes and thus improve sustainability in this sector through through tools such as Life Cycle Analysis (LCA) and cleaner production technologies, since customers have also become more aware of this issue and therefore more demanding with the products they purchase. Also, since the vast majority of forms of business pollution equate to economic loss, businesses will be more motivated to make more efficient use of resources. In this way they will be able to reduce their operating costs and therefore increase the economic competitiveness of the company. It is for all these reasons that the strategic prospective of the copper mining industry will contribute to the improvement of sustainability in Peru.

3. Methods

The present investigation includes a prospective-mixed approach. The mixed-type approach was used because our study subject characteristics will be analyzed and explored, later, aspects related to the variables and future scenarios will be quantified. The methodological strategy (Table 1) used was divided into three parts with various objectives that will be written below. Diagnosis, Identification and Validation of variables, Structural Analysis and Validation of findings; the following table details the objectives, techniques and units of analysis for each of the phases.

Table 1. Methodological strategy

Type	Mixed with the French strategic prospective			
Study subject	Copper mining industry in Peru			
Phase	0. Diagnosis	1. Identification and validation of variables	2. Structural analysis	3. Finding's validation
Objectives	Cognize the current situation of the mining industry in Peru.	Cognize the variables with which it is related to the improvement of the environmental sustainability of the copper mining industry in Peru.	Determine the key variables.	Generate future scenarios.
	Cognize the copper production process, its inputs and outputs and its main problems.			
	Determine and characterize the environmental impacts and strategic planning of the sector.	List and describe the variables found.	Analyze the relationships between actors and their stated objectives.	
Techniques	Review of theoretical and contextual framework, Porter and PESTLE analysis (Obj. 1).	Semi-structured interviews (Obj. 1 y 2).	MICMAC software (Obj. 1).	SMIC-Prob-Expert software (Obj. 1).
	Sankey, Pareto, Ishikawa diagram and Strategic Map (Obj. 2).			
	Life Cycle Analysis (LCA) and Characterization Diagram (Obj. 3).	Delphi method (Obj. 1 y 2).	MACTOR software (Obj. 2).	
		Coding of variables (Obj. 2).		
Analysis unit	Papers (Obj. 1, 2 y 3).	Papers (Obj. 1 y 2).	Specialists and academic experts in the sustainability of the copper mining industry in Peru (Obj. 1 y 2).	Specialists and academic experts in the sustainability of the copper mining industry in Peru (Obj. 1).
		Representatives of the mining sector whose companies are focused on copper mining production (Obj. 1).		

According to the Delphi methodology, for the selection of the experts in our panel, 8 relevant people were considered for our research topic, since it is not advisable to consult more than 30 experts, since the increase in the forecast is very small and the increase in research cost does not compensate for the improvement (Reguant and Torrado 2016). Regarding the profile of the selected experts, those people who corresponded to the specialist profile were taken into account (Reguant and Torrado 2016). Therefore, the selected people must meet at least one of the following characteristics: Professional experience of more than 5 years in the most representative mining companies in the country or higher academic studies in the mining industry field related to environment, water resources, safety and occupational health issues. On the other hand, semi-structured interviews were conducted to review and determine the variables raised above; for this, an interview guide was designed with 62 questions related to each variable. This instrument was validated by a prominent member of our panel of experts. The application of these interviews was carried out through video calls, since it was not possible to do this in person due to Covid-19. This process was carried out anonymously among the experts. Posteriorly, the key variables were determined by means of the MICMAC software, according to Riveros and Silva (2008), these are called key-variables or challenge variables of the system, because they are very motor and dependent on each other. They disrupt the normal functioning of the system, are unstable by nature and correspond to the challenges of the system. For this, the 31 variables were entered in the software, each one with its description; then, the direct influence table was inserted, the experts previously made the score between these variables from 0 to 4, with 0 being "no influence", 1 with "weak influence", 2 with "moderate influence", 3 with "strong influence" and 4 with a "potential influence". From this, the matrix of direct relationships was obtained, in which six key variables must be identified. Likewise, to carry out the game between actors, the MACTOR software was used. The first step was to enter the list of actors, each with their description. Then the objectives set for each variable were inserted. Afterwards, the influence matrix between actors was introduced, in which previously the score from 0 to 4 was made taking into account the importance of the effect on the actor, where 0 is "no influence", 1 is "processes", 2 is "projects", 3 is "mission" and 4 is "existence". Finally, the rating that each actor had previously made on each objective was inserted, this score being from 0 to 4, with 0 being "inconsistent objective" and 4 "the objective is indispensable for the existence of the actor". From this, the plane of influences and dependencies between actors was obtained. Finally, to generate future scenarios, the Smic-Prob-Expert software was used, where the key variables were introduced first, each one with its respective hypothesis. Then the ratings, between 0 and 1 of each expert were inserted about how likely it was that each hypothesis would be given. Afterwards, the qualification of the probabilities of yes realization between variables between 0 and 1 were introduced, this means that each expert rated according to how likely is that the hypotheses of each variable will be fulfilled, in case the others are fulfilled. In the same way, the rating of the probabilities of no realization between variables were inserted, according to how likely it is that the hypotheses of each variable are fulfilled, in case the others are not fulfilled. From this, the probability histogram of scenarios of the group of experts was obtained.

In the next part, the research methodology (Figure 2) will be presented, in which the research process can be appreciated from start to finish.

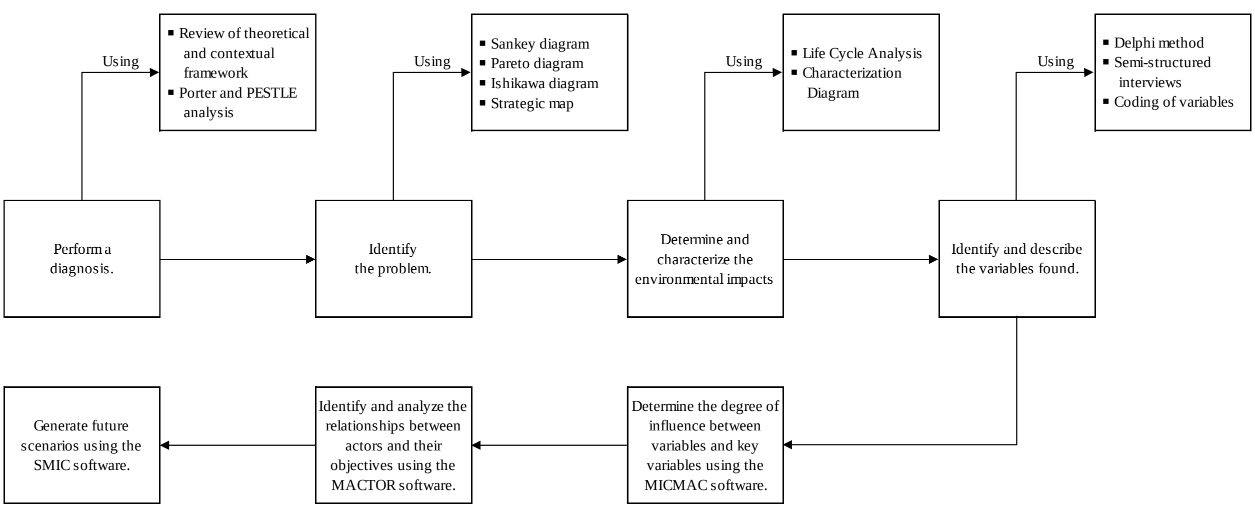

Figure 2. Investigation methodology

4. Data Collection

Below, you can see the Life Cycle Analysis (Figure 3), which was prepared in order to determine and understand in a more rigorous way the environmental aspects and impacts that are generated in each stage of the copper production process. This data was collected from Hong et al. (2018) and Davenport and Partelpoeg (1987).

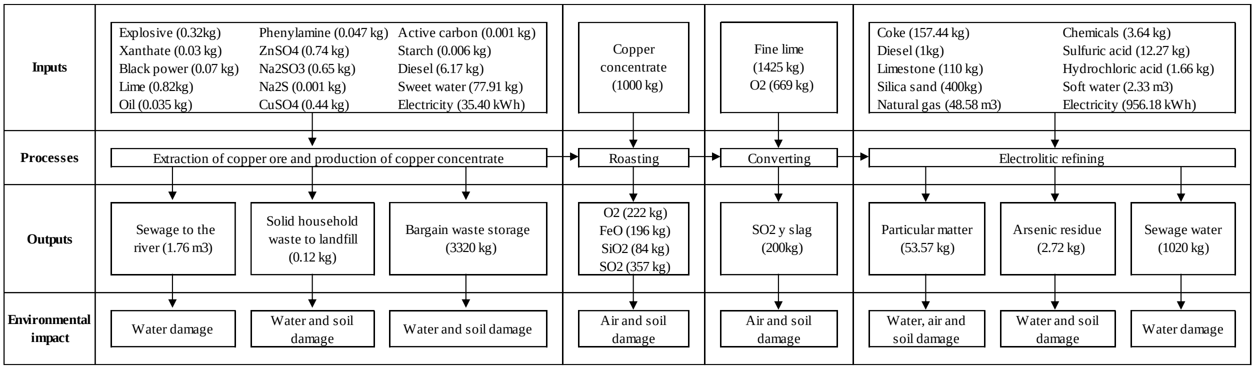

Figure 3. Life Cycle Analysis (LCA)

With the application of techniques, tools and meetings with experts, the following variables related to copper mining in Peru were defined then they were coded for further processing (Table 2). The descriptions were made based on scientific articles and were validated by one of our experts.

Table 2. Coding of variables

Variable	Code	Variable	Code
Environmental Management System	Sist_Gam	Process management	Gest_Proc
Environmental performance	Des_Amb	Innovation Management	Gest_Innov
Environmental legal regulations of the country	Nor_LegAmb	Strategic planning	Plan_Est
International legal standards	Norm_LegInt	Lean Production	Lean_Prod
Clean technologies	Tec_Limp	Production system automation	Aut_SistProd
Clean energies	Energ_Limp	Research and product development	Inv_DesPro
Cleaner production	Prod_ML	Digital transformation	Trans_Dig
Impurities in copper concentrates	Imp_ConCCu	Ecolabel ISO 14021	Eco_ISO
Generation of granulated slags	Gen_Esc	Detailed Environmental Impact Study	Est_IAmbDet
Greenhouse gas generation	Gen_GasEfInv	Use of Big Data y Business Intelligence	BigD_Bint
Atmospheric pollution (SO2 y PM)	Cont_Atm	Sustainable mining	Min_Sost
Corrective approach to contamination	Enf_Ccont	Operating costs	Cost_Oper
Social conflicts	Conf_Soc	ROI (Return on Investment)	Ret_ Sinv
Political risk	Riesg_Pol	Corporate image	Imag_Corp
Organizational culture aimed at preventing pollution	COrg_PrevCont	Legal stability	Etab_Jur
Organizational Cost Leadership Strategy	Estrat_Lcost		

As explained in the methodology, the MICMAC software produced the following matrix (Figure 4) for the identification of the six key variables in the upper right quadrant: Impurities in copper concentrates, Detailed Environmental Impact Study, Lean Technologies, leaner Production, Organizational culture oriented to the prevention of contamination and Sustainable Mining. On the other hand, those that are in the lower right quadrant are recognized as result variables: Corporate image, social conflicts, operating costs, legal stability, political risk and automation of the production process. Both variables show a high degree of dependence, but the key variables also have a similar level of independence; meaning that while the key variables are the determining factors that guide the sector's behavior, the result variables are the consequence of everything that is implemented in it.

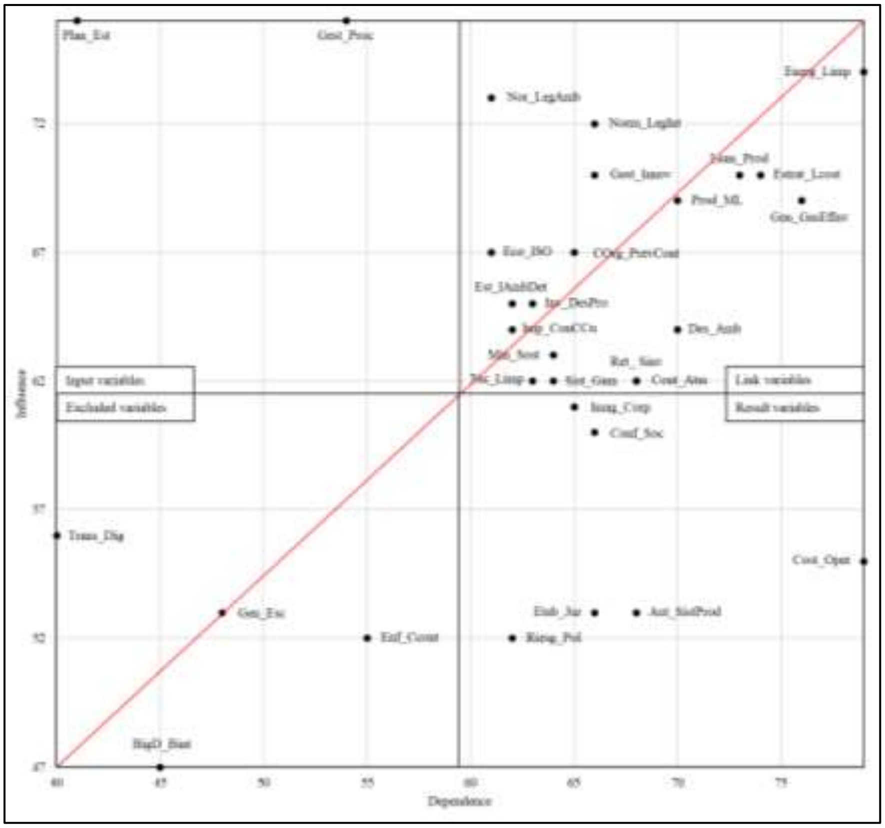

Figure 4. MICMAC Matrix

For the MACTOR software, four relevant actors for the sector were defined; for this, we consider the areas of the most important mining companies according to our experts, each area corresponds to the area of experience of at least two experts: environmental area (AMB_A1), mining engineering area (INGMIN_A2), quality area (CAL_A3) and production area (PROD_A4). Then, the long-term objectives for each of these key variables will be showed (Table 3).

Table 3. MACTOR objectives

Variable	MACTOR objectives
Imp_ConCCu	Minimize impurities in copper concentrates.
Est_IAmbDet	Prepare EIA using leaner production tools and circular economy to manage environmental aspects in a sustainable way.
Tec_Limp	Invest in emerging technologies that contribute to the optimizing of the production process.
Prod_ML	Implement the PML at a strategic level to improve environmental performance.
COrg_PrevCont	Implement the philosophy of PML and lean manufacturing throughout the organization to contribute to the sustainability of the company.
Min_Sost	Adapt environmental performance to international LMPs, achieve competitive profitability levels, good relationships with interested parties.

When evaluating the effects of each objective on each of the actors, the matrix of influence and dependence among them was obtained (Figure 5); this showed that the most relevant actors for the established objectives are the environmental area (AMB_A1) and the production area (PROD_A4) for having a high influence and dependence, since they are in the upper right quadrant in which the link actors are located. Likewise, the Mining Engineering area (INGMIN_A2) is very independent since it is located in the power zone. Finally, the Quality area (CAL_A3) has little influence since it is in the lower right quadrant.

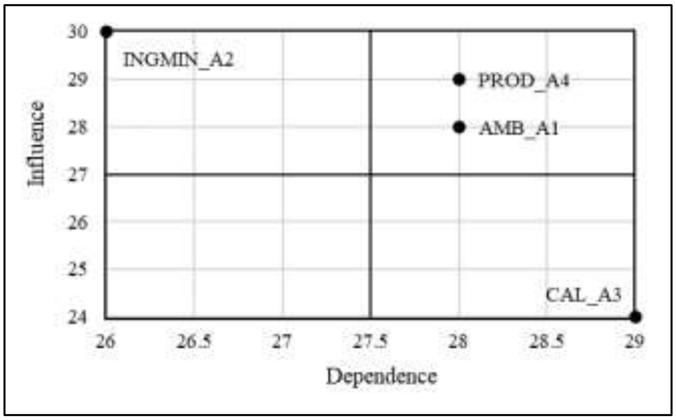

Figure 5. Matrix of influence and dependence among actors

With the second valuation, the position of the actors over the objectives is shown in the histogram of actor's implication towards its objectives - 2MAO (Figure 6). It showed that any actor opposed to any of the defined objectives and that the two objectives in which there are the greater acceptance are those related to impurities in copper concentrates (Imp_ConCCu) and the detailed environmental impact study (Est_IAmbDet).

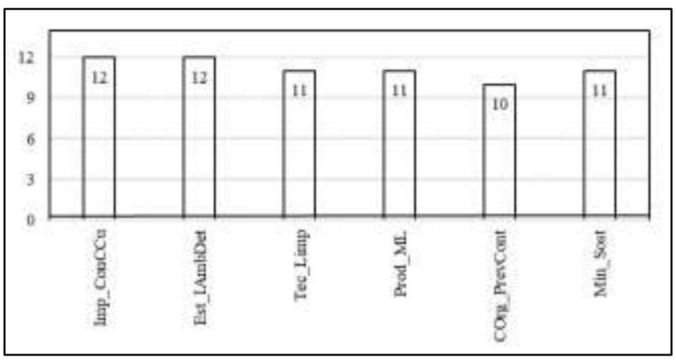

Figure 6. Histogram of actor's implication towards its objectives - 2MAO

5. Results and Discussion

5.1 Graphical Results

For the Smic-Prob-Expert software, 4 hypotheses were defined for each of our variables (Figure 7), these hypotheses were addressed by the same theme for each variable, differing in the effect they could have, considering the null effects (Hypothesis 1), probable (Hypothesis 2), positive (Hypothesis 3) and very positive (Hypothesis 4). Subsequently, the experts were asked to choose a single hypothesis per variable that guarantees the sustainability of the mining industry; for all variables, hypothesis number four was selected, with the exception of the variable impurities in copper concentrates (Imp_ConCCu), whose selected hypothesis was number three. The selected hypotheses were those that were entered into the software for the experts to rate the probability of their occurrence.

Variable	Hypothesis 1	Hypothesis 2	Hypothesis 3	Hypothesis 4
Imp_ConCCu	The implementation of sustainable purchases does not allow to minimize impurities in concentrates.	The implementation of sustainable purchases could make it possible to minimize impurities in concentrates.	The implementation of sustainable purchases allows to minimize impurities in concentrates.	The implementation of sustainable purchases allows to eliminate impurities in concentrates.
Est_IAmbDet	The preparation of an Environmental Impact Study, considering the principles of circular economy and sustainability, does not allow the development of sustainable copper mining projects.	The preparation of an Environmental Impact Study, considering the principles of circular economy and sustainability, could allow the development of sustainable copper mining projects.	The preparation of an Environmental Impact Study, considering the principles of circular economy and sustainability, allows developing sustainable copper mining projects.	The preparation of an Environmental Impact Study, considering the principles of circular economy and sustainability, allows optimizing sustainable copper mining projects.
Tec_Limp	The application of clean technologies in smelting and conversion processes does not reduce emissions, discharges and waste.	The application of clean technologies in smelting and conversion processes could reduce emissions, discharges and waste.	The application of clean technologies in smelting and conversion processes reduces emissions, discharges and waste.	The application of clean technologies in the smelting and conversion processes allows to minimize emissions, discharges and waste.
Prod_ML	The implementation of cleaner production at the strategic level applying strategies level 1 (source and raw material) and level 2 (residual emissions) do not improve the environmental performance of the company.	The implementation of cleaner production at the strategic level applying strategies level 1 (source and raw material) and level 2 (residual emissions) could improve the environmental performance of the company.	The implementation of cleaner production at the strategic level applying strategies level 1 (source and raw material) and level 2 (residual emissions) improve the environmental performance of the company.	The implementation of cleaner production at the strategic level applying strategies level 1 (source and raw material) and level 2 (residual emissions) maximize the environmental performance of the company.
COrg_PrevCont	The implementation of a culture oriented to the prevention of pollution does not allow to improve the environmental performance of the company.	The implementation of a culture oriented towards the prevention of pollution could improve the environmental performance of the company.	The implementation of a culture oriented to the prevention of pollution allows to improve the environmental performance of the company.	The implementation of a culture oriented to the prevention of pollution optimizes the environmental performance of the company.
Min_Sost	The implementation of the circular economy philosophy (clean techonologies, energies and production and lean production, etc.) does not allow to improve the social and economic environmental performance.	The implementation of the circular economy philosophy (clean techonologies, energies and production and lean production, etc.) could improve social and economic environmental performance.	The implementation of the circular economy philosophy (clean techonologies, energies and production and lean production, etc.) allows improving the social and economic environmental performance.	The implementation of the circular economy philosophy (clean techonologies, energies and production and lean production, etc.) maximizes social and economic environmental performance.

Figure 7. SMIC hypothesis

The figure 8, provided by the software, shows the probabilities of occurrence of the ten best scenarios. Each scenario is defined by the occurrence of each of the hypotheses selected for the variables, being the value 1 the one that corresponds to the occurrence and the value 0, the non-occurrence. 64 possible scenarios were obtained, of which the first scenario was chosen, with a probability of 0.481, where all the hypotheses fulfilled, which agrees with the hypothesis that the strategic prospect of the copper mining industry in Peru will contribute to the improvement of environmental sustainability. However, given that the probability is less than 70%, the level of demand for the hypotheses related to clean technologies and cleaner production will be lowered. Likewise, it can be noted that the three hypotheses that had the highest probability of occurrence were those related to the variable of impurities in copper concentrates, detailed environmental impact study and clean technologies, in that order.

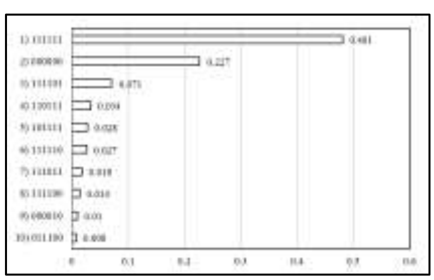

Figure 8. Scenario probability histogram (Expert Pool)

The occurrence of these scenarios would positively impact the strategic planning of copper mining companies, allowing progress in all the perspectives included in the strategic maps below (Figure 9); this shows that the improvement of the sustainability of companies has a positive impact in a comprehensive manner, especially in financial indicators such as ROI, enabling investment in other strategic areas.

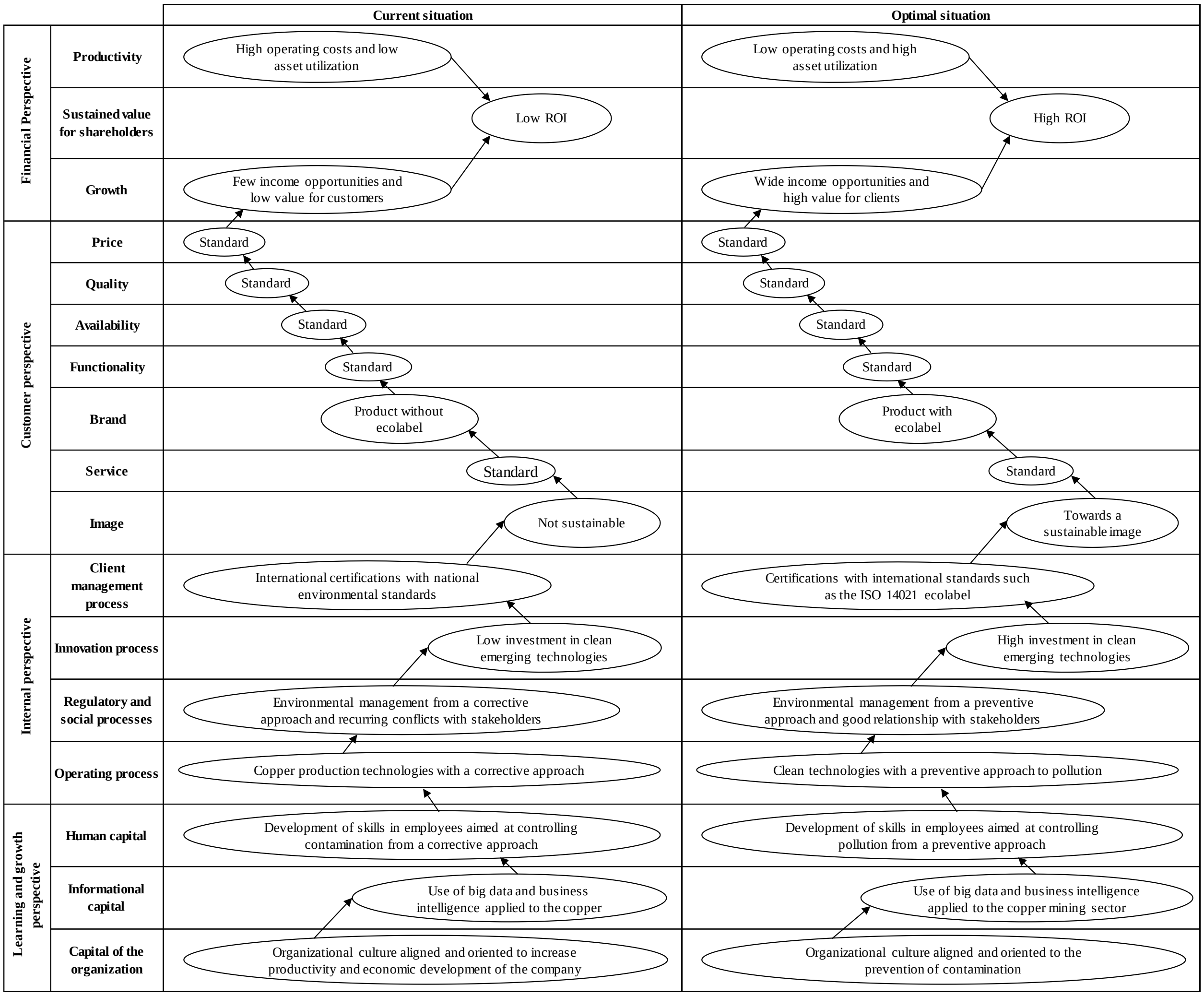

Figure 9. Strategic maps: Current situation vs. Optimal situation

5.3 Proposed Improvements

The Environmental Impact Study is the most relevant factor for the study, and it can be seen in the graph (Figure 10) how the other variables contribute to the strategic planning of the company. In the same way, the Balanced Scorecard, the strategic map and the Life Cycle of the project contribute to generate a sustainability scenario. Also, the findings show that not only the stakeholders of the copper mining industry can adopt the obtained sustainability scenario, but it can also be used in companies at an international level in all sectors that involve some transformation processes.

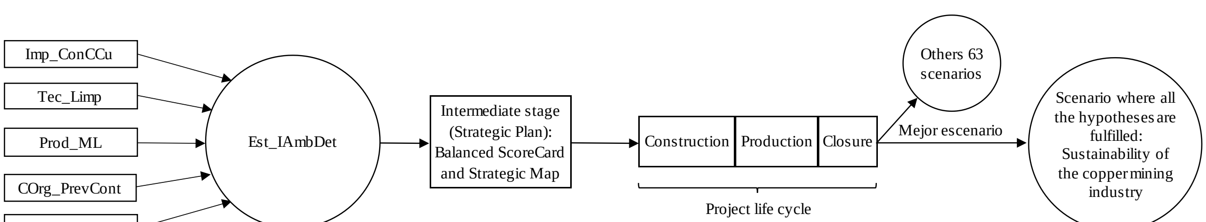

Figure 10. Sustainability scenario

6. Conclusion

Compliance with the general objective is verified, which is the identification of possible future long-term scenarios. Likewise, regarding the first specific objective, the diagnosis of the current situation of the copper mining industry indicates that it has high levels of emissions of gases and particulate matter that in many cases exceed the LMP. Regarding the second specific objective, 31 variables were identified, which were validated by the experts. Also, in the third specific objective, the structural analysis was carried out, where the 6 key variables were determined and the relationships between actors were analyzed. Finally, in the fourth specific objective, the validation of findings was carried out where 64 future scenarios were generated. According to experts, the combination of the 5 variables within the EIA will allow achieving sustainable copper mining, which would be the best scenario. Therefore, for shareholders to be able to migrate towards a sustainability scenario, they must rethink the way in which the Environmental Impact Study (EIA) is going to be reformulated, in other words, the project must be oriented with a preventive approach on contamination and not from a corrective one.

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