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FACULTAD DE INGENIERÍA

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TESIS

Methodological proposal for an optimal management of Social-Ecological Systems in relation to large-scale mining in Peru

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Para optar el Título Profesional de
Ingeniero Ambiental

Huancayo - Perú
2025

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Título:
Methodological proposal for an optimal management of Social-Ecological Systems in relation to large-scale mining in Peru

URL / DOI:
https://doi.org/10.1051/e3sconf/202561203004

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Methodological proposal for an optimal management of Social-Ecological Systems in relation to large-scale mining in Peru

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Abstract. Significant participation of mining activities in the economic indicators of countries and extraction of raw materials to produce goods is relevant to evaluate management of the social-ecological systems in which they operate. This article proposes a methodology that integrates design principles (resource use rules), resilience principles (adaptive strategies that respond to disturbances) and principles linked to good practices promoted in the sector. Under this proposal, it is considered that design principles and resilience principles guide management of organizations and constitute pillars that strengthen organizational capabilities, the latter being the essence for optimal management of SES. Peru is characterized by its leading position in world ranking in mining production and reserves. Through the proposed methodology, this article studies mining companies considering value of mining production, mineral diversification and participation of companies in the mineral production, resulting that the optimal management of SES, in relation to large-scale mining, is "in development", with partial compliance.

1 Introduction

Peru is among the top ten countries in the world ranking for metallic mining production[†] and mining reserves of gold, copper, silver, zinc, lead, tin and molybdenum [1]. With a population of 33.7 million people, it is located on the central coast of South America facing the Pacific Ocean, the Central Highlands crosses its territory, and 75% of its territory is Amazon basin, which allows it to be divided geographically into three regions - Coast, Highlands and Amazon Jungle - and the country's main mineral deposits are located in the Highlands [2-4]. In addition, Peru is considered a hub in the Pacific basin, where large-scale port and airport infrastructure development is increasing trade with other continents [5,6]. Among the main export commodities are copper, gold, zinc, fishmeal, paper, chemical products, and agricultural and livestock products [7].

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[†] 41% of Peruvian territory comprises restricted areas to mining activities such as natural areas of indirect use, fragile ecosystems, archaeological zones, urban areas, others. Approximately 10% of the national territory has mining vocation, 1.34% of which is in current activity [1].

The mining sector is key to the national Gross Domestic Product (GDP). At the beginning of the 1990s, when Constitutional changes took place in the economic chapter, the mining GDP represented an average of 7.5% of the total GDP, then from 1995 to 2005 its contribution to the national GDP increased steadily, reaching 11.6% (historical maximum), and later from 2006 to 2011 its representation was reduced and then recovered in the following five-year period. Subsequently, the mining GDP has been maintained, without surpassing its historical values, mainly affected by political instability and inefficient management in the face of the COVID-19 pandemic [8]. The COVID-19 pandemic generated a shock in mining production as well as in mineral prices, which in the last two years (2022 and 2023) have gradually recovered, reaching pre-pandemic levels of contribution to GDP. On average, between 1990 and 2023, this sector represented 8.9% of GDP and its share in total exports, in the period 2002 - 2023, exceeded 50% (see *Figure 1*).

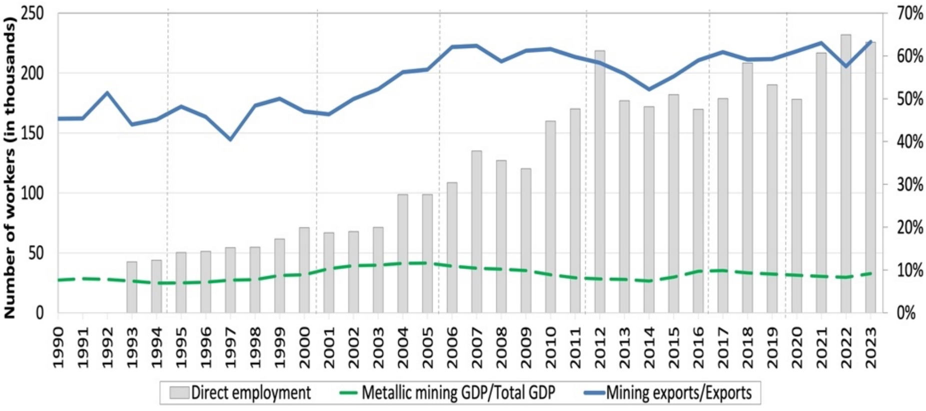

Fig. 1. Evolution of macroeconomic variables (1990-2023).
Source: Own elaboration based on information from the MINEM [1], BCRP [7], IIMP [10].

Likewise, large-scale mining is a capital-intensive sector and a source of jobs directly through the mining owners and contractors themselves, and according to the Peruvian Institute of Economics [9], mining generates an estimated multiplier effect‡ of 8 additional jobs for each direct job. In 2023, an average of 225 thousand direct jobs were generated [1], which would have resulted in more than 1.8 million additional jobs. In this regard, mining in Peru is classified into four strata: artisanal, small, medium, and large-scale mining; in the latter category, the production capacity must be greater than 5 thousand metric tons per day [11]. The production of gold, zinc, copper, silver, and lead is mainly concentrated in large and medium mining, ranging from 84 to 99% of the total [1].

1.1 Social-ecological systems (SES)

Different authors have contributed to the concept of SES, Ostrom [12] mentions that the characteristics of SES are complex, multivariable, nonlinear, cross-scale and changing systems, also Bruno and Ferrer [13] add that SES have different levels of uncertainty, where the human dimension is constantly redefining ecosystems, and ecosystems in turn influence human decisions. In this ecosystem-social system interaction, matter, energy and information are constantly exchanged, reflecting the dynamics of each system and highlighting the impact

‡ The multiplier effect includes the indirect and induced effects (consumption and investment) of mining operations on employment generation in transportation of mining inputs, personnel and products, professional services, vehicle maintenance, food, education, construction, manufacturing, others [9].

of human activities on ecosystems [14]. It follows from the above that the aforementioned characteristics of SES dynamize intra- and inter-system functioning, as occurs in organizations, to achieve their objectives.

1.2 Design principles (DP)

Essential elements or conditions that helps to account for the success of social institutions in sustaining the common-pool resources and gaining the compliance of generation after generation of appropriators to the rules in use [15].

1.3 Resilience principles (RP)

Principles that enhance the capacity of an SES to continue to provide key ecosystem services to sustain well-being in the face of ongoing disturbance and change [16].

1.4 Sustainability

It involves management of interaction between society and ecosystems, considering social, environmental, and economic aspects, to meet the needs of current and future generations [17-19]. From a procedural perspective, sustainability is the management (decisions, actions) that precedes the outcome: satisfaction of needs (sustainable development§).

1.5 Management

It is a dynamic, complex, and flexible process, which integrates rules, processes, activities, where through the coordination of human, technical, and financial resources, organizational objectives are achieved [17, 20-22]. Thus, it follows that management implies a framework of rules and norms that guide organizations, together with the development of adaptive strategies for the coordination of their resources, to achieve their objectives.

1.6 Optimal management of SES

By considering SES as partially decomposable systems, it follows that their management implies a holistic, interdisciplinary perspective and a normative framework based on stakeholder negotiation. Moreover, SES operate at specific spatial and temporal scales, which implies adaptability and the need for new ways of learning on the part of participants [12]. The present research focus on the use of design principles (linked to resource use rules) and resilience principles (linked to adaptive strategies that respond to perturbations and continuous changes), for a methodological innovation that is useful in the diagnosis and implementation of the management of SES linked to an extractive activity.

2 Methods

Methodology is described in Figure 2.

§ Brundtland Report defines it as meeting the needs of the present without compromising future well-being [23] and includes economic, social, and environmental dimensions [24].

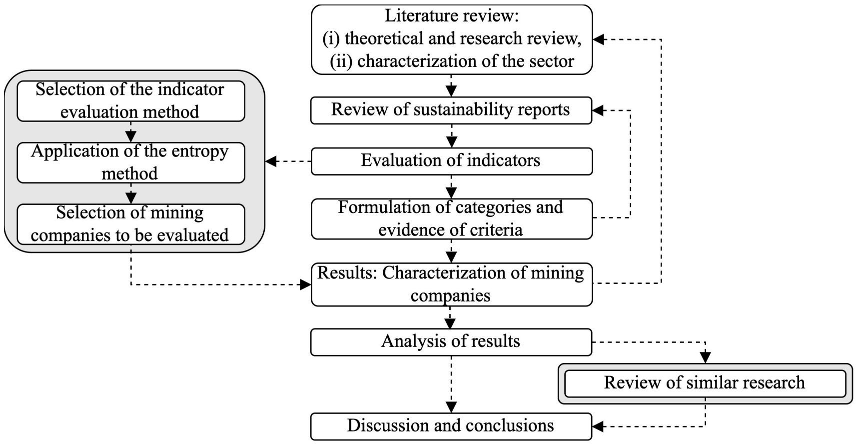

Fig. 2. Methodological approach.
Source: Own elaboration adapted from Alves et al. [25].

2.1 About the principles used

To contribute to an optimal management of SES in relation to large-scale mining in Peru, DP and RP were used, both complement and feedback into the analysis of the sustainability of resource use, also explains sustainability on a social-ecological scale goes beyond community organizations. So, it is needed to select principles that can be applied on larger spatial-temporal scale, considering nature and characteristics of each economic activity. Due to the nature of mining and its products (minerals), this is a key sector to investigate, especially in countries like Peru because of the importance of its contribution to the economic dynamics. Table 1 shows the DP and RP selected for this methodology proposed.

Table 1. Selected design and resilience principles.

Principles selected	Detail
DP based on Ostrom [15]	DP 1. Clearly defined boundaries: Stakeholders (State, mining companies, communities) involved access and understand the meaning of the normative.
	DP 2. Congruence: Stakeholders perceive that the regulations are favorable to them and that they are designed considering the characteristics of the SES.
	DP 4. Monitoring: Involves the participation of all stakeholders.
RP based on Cambridge University Press publication [16]	RP 4. Foster complex adaptive systems thinking: The holistic perspective should be prioritized, which includes the interdisciplinarity and knowledge based on experience.
	RP 5. Encourage learning: The past experiences of SES should be a guide for an intelligent decision making.
	RP 6. Broaden participation: Diversity of stakeholders participating in ecosystem services management in ways that enhance legitimacy, broaden the range and depth of knowledge, and help identify and interpret disturbances.
	RP 7. Promote polycentric governance systems: Implies the decentralization of the decision making, where the directly involved stakeholders have the optimal organizational capabilities.

Source: Own elaboration based on: Ostrom [15] and R. Biggs, M. Schlüter, M. Schoon [16].

From the definitions of DP and RP, both contribute to the optimal management of the SES to approach their sustainable development. The former from a normative perspective and the latter in terms of the strategies to be adopted in the face of disturbances and continuous changes. Also, considering that the focus of this article is oriented to large-scale mining, the principles of the International Council on Mining and Metals (ICMM) were included, which establish requirements for good environmental, social and governance practices to be followed by the members of companies belonging to the mining and metallurgical industry [26], i.e. closely linked to management from a business perspective, as proposed in the research by Moran et al. [27]. From the analysis of these three sets of principles, an adaptive, constant learning, interdisciplinary and holistic approach is achieved, which accounts for the complexity of the mining activity. Thus, the integration of design, resilience and ICMM principles allows for a complete vision to analyze the management of SES linked to large-scale mining in Peru. After a comparative analysis and in relation to the context of SES in Peru, three DP and four RP related to the three dimensions of sustainable development: environmental (En), economic (Ec), and social (S), were selected.

2.2 Indicator evaluation method for company selection

Indicators must be representative, scientific, and accessible, so that they allow the evaluation system to be built [28]. The weight of an indicator represents its relative importance as well as its contribution to the system [29]. Indicators selected are detailed on Table 2.

Table 2. Indicators for the selection of mining companies.

N°	Indicators	Weight*
I_1	Mineral diversification	0.2
I_2	Company's share of total ore production (2016-2022)**	0.1
I_3	Value of mining production (2016-2022)**	0.7

Notes: * For practical purposes in the analysis, percentage values were rounded.
** For the calculation of the two indicators, I_2 and I_3, the period 2016-2022 was considered due to the fact that large mining operations began large-scale exploitation of minerals, which have positioned themselves over time. Likewise, 2020 is included as a year that allows us to see the strategies and responses of mining companies in the face of an event (Covid-19 pandemic) that affected the world economy and population dynamics. Since 2023 information is in process of being published by mining companies and government sources, so this year was not included for analysis.

2.2.1 Indicator selection

Geological potential reflects a country's capacity to produce minerals for the domestic and foreign markets (exports) and is thus a determinant of the country's competitiveness and an attractive factor for investment [30]. Peru is among the top ten countries in the world ranking of mining reserves of copper, gold, zinc, silver, lead, tin, and molybdenum, which reflects the global importance of these reserves. This geological potential is reflected in the variety of mining companies that have operations where they exploit various mineral products, which shows the importance of indicator I_1. In line with the large reserves of various minerals, Peru occupies the first positions in world production of these metals, where companies are decisive in the country's total production. Therefore, indicator of participation (I_2) and value of mining production are important (I_3).

2.2.2 Calculation the weight of indicators

To determine the weight of the indicators, the entropy method was used to ensure objectivity in assigning weights to the indicators. This method proposes an inverse relationship between the disorder of the indicator (wide distribution/diversity of the indicator data) and the entropy of the information (disorder in the system); when the disorder is greater, it implies that the indicator provides more information, and therefore the effect on the system is greater [28]. Delgado and Romero [31] used this method to analyze environmental conflicts in Peru.

i) Normalize by the sum of the values of each indicator.

$$P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{n} X'_{ij}} \quad (1)$$

Where P_{ij} represents the value of criterion j in company i, X'_{ij} represents the standardized value of criterion j in company i, and n represents the total number of large-scale companies.

ii) Calculation entropy of each indicator:

$$e_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} (P_{ij} * lnP_{ij}) \quad (2)$$

iii) Calculation weight of each indicator:

$$w_j^* = \frac{1-e_j}{n-\sum_{i=1}^{n} e_i} \quad (3)$$

From the review of mining statistics in Peru prepared by the Ministry of Energy and Mines, the sector's governing body, the total number of large mining companies that operated during the period of analysis (2016-2022) was counted, in addition, the metals that are exploited in their different mining operations, the annual production volume and the value of production equivalent to the sum product of the annual production volume and the annual average daily quotation of mining products were identified. Applying the calculations described above, weights of indicators in Table 2 were obtained.

2.2.3 Selection of companies

Using the obtained indicator weights, the companies were selected, and each one was characterized with information linked to the criteria in Table 3. It implied a review of Peruvian mining companies' publications like sustainability, economic-financial and technical reports, also their web sites and government databases from 2016-2023, identifying that the information for 2023 was being developed at the time of the elaboration of the research and was therefore not accessible. Then, the results were integrated for a sectoral analysis regarding the optimal management of SES in large-scale mining.

2.3 Formulation of categories and evidence of criteria

Based on the design and resilience principles outlined in Table 1 along with the dimensions of sustainability, possible categories were identified. Then, the available information from a significant number of mining companies was reviewed and a preliminary characterization of each one was elaborated, adjusting these categories according to aspects in common. Later, the criteria corresponding to each of the categories were formulated based on a review of research and regulations, improving preliminary characterization until a solid characterization of selected companies (see *Figure 3*) was obtained under the indicators shown in Table 2. Also, ICMM principles were used as a reference and indirectly with standards of Global Reporting Initiative, since these are used by Peruvian mining companies for the disclosure of information through sustainability reports. Thus, with the matrix of principles, dimensions, categories, criteria, research references and characterization of selected mining companies, the compliance of the selected companies was calculated, considering whether they met two or more criteria, one criterion or no criteria. These results are shown in Table 3.

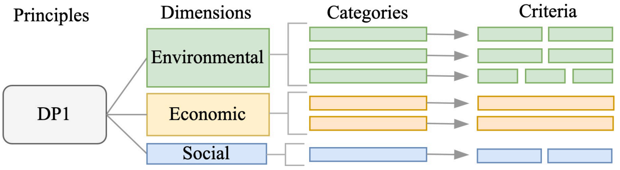

Fig. 3. Example of formulation of categories and evidence of criteria
Source: Own elaboration

3 Results

Table 3. Criteria for the characterization of mining companies and fulfillment

Principles-Dimension	Categories	Criteria	Ref.	Fulfillment (expressed in percentage and/or qualitatively)		
				2 or more criteria	1 criterion	No criterion
DP1- En	Environmental monitoring	i) Participatory, ii) comprehensive (measurement of water quality, air, noise, or vibrations).	[26]	22	33	45
	Application of the Mitigation Hierarchy	i) Scope of attention to ecosystemic elements, ii) synergy of strategies established by mining operations in contribution to ecosystemic health.		22	45	33
	Mine closure [35]	i) Budget programmed and executed, ii) supporting documents, iii) set of actions executed if applicable.	[26], [32], [33]	33	45	22
DP1- Ec	Tax payments	Not applicable, data on the sector's contribution to the national economy is presented.	[33], [34]	Approximately a payment of US$ 3.84 billion dollars (2016-20).		
	Payment of regulatory fees [36]			Approximately a payment of US$ 157.4 million dollars (2016-20).		
DP1- S	Access to information [37]	i) Number and ii) location of Permanent Information Office(s) and/or Participatory Environmental Monitoring and Surveillance Committee(s).	[26], [34]	11	22	67
DP2- Ec	Local purchase of inputs	Not applicable, data on the sector's contribution to the national economy is presented.	[26], [33]	5 mining companies paid a total of US$ 2.39 billion, evidencing a growing trend over time (2016-20).		
	Works for Taxes Scheme		[34]	55 projects have been awarded and/or concluded covering 35% of the country's Regions, for a total amount of US$ 559.9 million in projects in agriculture, solid waste, commerce, others (2016-20).		
	Local employment [38]		[33], [34]	45% were local employees, a growing trend was maintained until 2019.		
DP2- S	Consultation and grievance processes	i) Procedure for handling claims and complaints, ii) statistics on these claims, iii) training to strengthen the organization of communities linked to the RP4.	[26], [33]	45	33	22

Table 3. Continued

Principles-Dimension	Categories	Criteria	Ref.	Fulfillment (expressed in percentage and/or qualitatively)		
				2 or more criteria	1 criterion	No criterion
DP4- En	Monetary penalties [39]	Not applicable, sector data is presented with respect to sanctions imposed by the supervising environmental agency.	[26], [33], [34]	21% of a total of 174 supervisions involved the imposition of a fine, in the most frequent non-compliances were for environmental commitments and/or standards, deadlines for submitting monitoring and actions linked to environmental monitoring (2016-20).		
DP4- Ec	Monetary penalties	Not applicable, sector data is presented with respect to sanctions imposed by the taxation agency.	[33], [34]	During the period, 40 audits related to the payment of income tax (70%) and mining royalties (30%) were reported (2016-20).		
DP4- S	Occupational accidents	i) Accident statistics, ii) description of the accident and/or actions taken.	[26], [33]	11	78	11
DP4- En	Accidents in communities	i) Accident statistics, ii) description of the accident and/or actions taken.	[33]	11	33	56
RP4- En	Water management	i) Establishment of targets, ii) statistics on consumption, iii) water reuse.	[26], [33], [34]	56	22	22
	GHG management	i) Establishment of targets, ii) generation of GHG.		12	44	44
	Solid waste management	i) Establishment of targets, ii) generation of solid waste, iii) statistics on recycling as a measure within the framework of solid waste valorization [40].	[26], [32], [33], [34]	67	22	11
	Technological innovation	i) Technological initiatives, ii) diversity of the scope of initiatives (processes, controls on solid waste generation and emissions, others).	[32]	44	12	44
RP4- Ec	Economic-environmental interaction	i) Economic-financial strategies in the face of metal price variations, ii) calculation of the carbon and/or water footprint.	[34]	-	67	33
RP4- S	Social conflict	i) Management of social conflict, ii) strengthening community organization.	[26], [34]	22	22	56
RP5- En	Training	Data is presented on training for communities, local authorities, university students, workers, others.	[34]	33% of the companies provided such training.		
RP5- Ec	Training on economic issues	Data is related training to strengthen the organization of local governments and their functioning.		22% of the companies provided training in public management and budgeting, financing, and others.		

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Table 3. Continued

Principles-Dimension	Categories	Criteria	Ref.	Fulfillment (expressed in percentage and/or qualitatively)		
				2 or more criteria	1 criterion	No criterion
RP5- S	Social management, dissemination, and training	i) Explanation of the social management model applied, ii) statistics on worker training, iii) dissemination of labor practices.	[26], [33], [34]	33	45	22
RP5-Transversal	Training and alliances	i) Amount invested in training, ii) partnerships established to strengthen training for communities, workers, and other stakeholders.	[33], [34]	11	67	22
RP6- En-S	Activities to strengthen stakeholders	i) Environmental management (participatory monitoring, reforestation activities, others), ii) promoting their participation.	[26], [32], [33]	44	56	-
RP7- En, Ec, S	Project management	i) Development of projects and/or activities oriented to water resources management, ii) presence of local knowledge in resources management, iii) projects financed or with contributions from companies.		11	78	11

Note: For the estimates of dollar values, statistics from the BCRP regarding the nominal and real exchange rate of soles (Peruvian national currency) to dollars have been used.

Using the values of fulfillment from Table 3, the percentages of compliance for each of the principles were averaged, it is evident that the percentage of mining companies that comply with one of the criteria is higher, reaching at least 50% in the case of DP4, RP5, RP6, RP7, as well as a higher compliance with 2 or more criteria for DP2 and RP6 (see *Figure 4*).

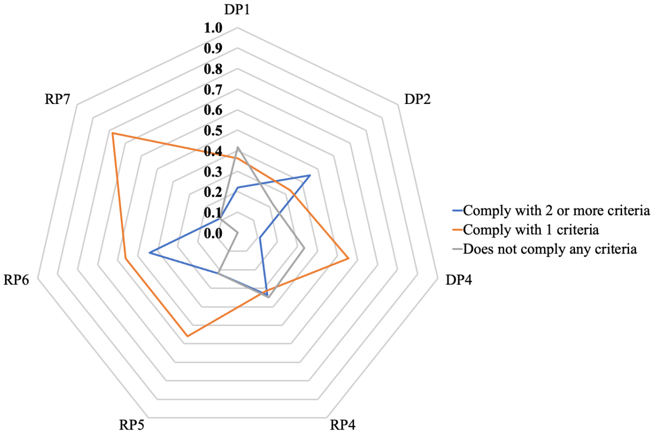

Fig. 4. Compliance with the criteria according to principles.
Source: Own elaboration.

Based on the average values of non-compliance with each of the principles, three ranges were established: [0-25%], (25-75%] and (75-100%], and they were qualitatively assigned three situations: not effective, in development, and consistent respectively, in line with Ferrer [41], the results of the analysis are displayed in Table 4.

Table 4. Results of the DP and RP analysis

Design Principles (DP)	Situation	Resilience Principles (RP)	Situation
DP1, DP4	In development	RP4	In development
DP2	Consistent	RP5, RP6, RP7	Consistent

Source: Own elaboration.

In line with the objectives of this research, it was considered that the approach should include an organizational configuration resulting from the interaction between the stakeholders: State, mining companies and communities, as it shows on Figure 5.

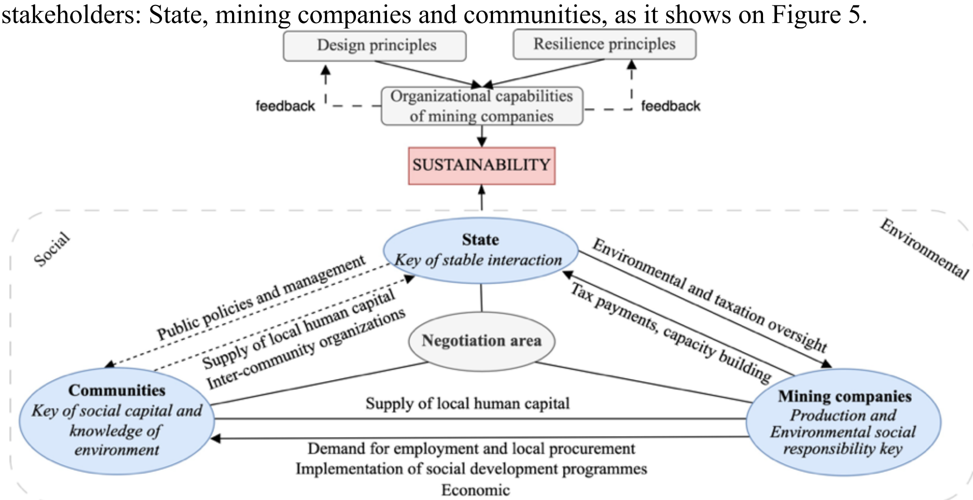

Fig. 5. A framework for SES analysis in mining sector.
Source: Own elaboration adapted from Brodny and Tutak [42] with contributions from Ostrom [15].
Notes: The solid lines indicate that the relationship has been analyzed in the research, the dotted lines indicate that there is evidence of this relationship, but it has not been analyzed in depth for this case.

So that from the interaction of the three stakeholders, the negotiation area corresponds to a space-time where stakeholders can plan, schedule, coordinate and dialogue. This creates a flow of information to establish rules and define adaptive processes that could strengthen organizational capacities. Thus, in order to improve their organizational capacities, each stakeholder will have to identify the level of compliance in order to redefine the standards and adaptive strategies, which involves making improvements in their mindset and in the working environment of mining companies, as well as the need to standardize the content of sustainability reports to demonstrate compliance with the categories.

4 Discussion

4.1 Discussion on methodology

Social-ecological analysis requires the interaction of scientific disciplines as well as the integration of methodologies that allow the study of social and environmental processes [43].

Aznar et al. [32] analyzed articles published between 1998 and 2017 on sustainability in mining, identifying that among Latin American countries, Chile stands out as the country that conducted the most research. Likewise, research on the environmental dimension is increasing when addressing the exploitation and closure phases, as opposed to the economic dimension, which is greater in the exploration phase. In the Peruvian case, research in the mining sector focuses on the social dimension through socio-environmental conflicts and mechanisms for their resolution, as highlighted in Polo y La Borda et al. [44], Saenz [45], Rey-Coquais [46]. Thus, it is evident that there is a need for several investigations that addresses the three dimensions of sustainability in an integrated manner.

Methodological antecedents of research in the mining sector such as those of Guzmán et al. [47] and Alves et al. [25] evaluate sustainability of this sector in Chile and Brazil respectively, focusing on the perception of experts (representatives of industry and academic institutions) regarding this activity and positive or negative impacts on economic, social, and environmental dimensions of their countries. On the other hand, the present research analyzes the information that mining companies communicate to stakeholders through sustainability reports, and with them the criteria that account for the selected principles are nurtured.

On the other hand, in European North and Northwest Russia, Suopajärvi et al. [48] highlight that in research, practice and policy decisions, less attention tends to be paid to social sustainability compared to the economic and ecological aspects of the mining sector. In addition, their research focuses on the procedural and contextual dimensions of social sustainability to analyze resource management; the former referring to the actual development of the mine and its continuity, related activities and residents' knowledge of operations and influence on outcomes, and the latter comprising the history, characteristics of localities and expectations. In this regard, the present research addresses the procedural dimension through: DP1, DP2, DP4, RP4, RP5, RP6, RP7, while the contextual dimension through: DP2, RP4, RP5, RP7, indicated in Table 3.

In this line, from the analysis of public statements on sustainability by national mining industry associations in different countries, Vivoda and Kemp [49] identified that Peru has policy statements with social aspects related to cultural heritage, community engagement, livehoods and food/water security, which have been incorporated in the DP2. Unlike Chile, which additionally includes human rights and support for vulnerable groups, or Mexico, which incorporates the latter, also local employment. Companies seek to incorporate sustainability into the design of their projects and systems. Based on the identification of opportunities and risks, action plans are formulated to support decision making. In relation to the identification, questions can be used to guide the formulation of objectives relating various aspects such as water consumption or production, gas emissions, local employment, skills development and diversity, community programs, zero waste and emissions systems, capital or operating costs and other aspects related to capital** [34]. The aforementioned aspects are distributed in the indicators shown in Table 3, as part of the methodology designed.

On the other hand, for the case of mining in Australia, Leyton-Flor and Sangha [50], the effects of mining activities on the environmental dimension include the degradation of environmental quality, and also emphasize that among stakeholder relations, communities need greater decision-making capacity and financial and technical resources for their actions in complex regulatory frameworks.

As Klayme et al. [51], mentions in his analysis for China, Australia, Russia, the United States and Canada, gold mining companies would be more sensitive to changes or uncertainties in economic conditions, which would affect investment decisions. This is consistent with the analysis carried out for Peru, regarding the implications of the rules

** Natural, human, social, manufactured and financial capital.

(design principles), the relationship between two stakeholders (State and mining companies) and the implications in the economic dimension.

4.2 Analysis of DP and RP

DP1: The clearly defined "in development" boundaries show partial compliance with participatory environmental monitoring, information disseminated on the Closure Plan, application of the mitigation hierarchy and means of access to information. Thus, considering the mining companies-community interrelationship, the mining companies could choose to provide more monitoring information on the stakeholders involved and other environmental factors monitored, other than water. In addition, the information in the Closure Plans is limited, it does not contemplate the integrality between financial execution and management activities and instruments, and the actions in the mitigation hierarchy are focused on prevention and remediation, without specifying mitigation actions.

The permanent information offices and environmental committees are the main means for access to information. At the same time, it shows that there is room for the formulation or reformulation of rules by the State. Following Ostrom [15], the area of interaction between the three stakeholders should safeguard the limits of mining activity, as well as the identification of the stakeholders and the expansion of the knowledge available to them.

DP2: Long-term sustainability depends on the congruence of standards with local conditions [52]. The "consistent" congruence shows that the companies under study carry out local purchases and employment, execute works through the works-for-taxes mechanism, provide information on the grievance procedure, results, and training to strengthen community organization. In this regard, Salem et al. [53] point out that government and company engagement with communities should begin at the earliest stage.

DP4: The long-term sustainability of the standards depends on their monitoring [52]. In this regard, supervision in Peru includes several areas such as environmental and labor, being that the companies have shown "in development" supervision, since the information disseminated in the reports does not incorporate both the statistics of accidents and the description of the same or the measures adopted; as well as the non-compliance with environmental commitments or standards that triggered fines.

RP4: Fostering complex adaptive systems thinking implies changes and adaptation in the fundamentals that support management processes and decision making [16]. In Peruvian large-scale mining this principle is "in development", which reflects that the information disseminated (establishment of goals, statistics) regarding the management of the outputs of the production process such as wastewater, GHG, solid waste, as well as technological initiatives is limited.

In addition, complex adaptive thinking implies accepting uncertainty, variability, and change [16], the results for Peruvian case reflect that economic-financial strategies in face of disturbances, as well as external interest in knowing results of carbon and/or water footprint, are aspects that need to be improved. Likewise, an improvement in management of social conflict will be achieved by strengthening a framework for articulation and negotiation, as well as developing activities that strengthen organization internally and among communities.

RP5: For this principle, there is evidence of learning with sufficient resources, networking, participation of stakeholders with multiple perspectives and experiences, which contributes to the resilience of the SES by influencing decision-making processes and governance [16]. The principle of stimulating learning is "consistent", considering that information disseminated includes statistics on training oriented to various stakeholders, their financing, and partnerships established for this purpose.

RP6: Participation implies active engagement of relevant stakeholders in the management and governance process, with clarity of objectives, roles and expectations, leadership, availability of human capital and financial resources [13]. In addition, communities share common knowledge about the attributes of the SES, how their actions affect each other, and the standards used in other SES, which would reduce organizational costs [49]. The results indicate that this principle is "consistent", given that the companies carry out activities with stakeholder participation such as monitoring, guided visits, dissemination of newsletters, etc.

RP7: “Consistent" polycentric governance shows that project management by companies is widespread, with less incidence on projects oriented to water resources management. In this regard, Carrillo [54] mentions that the State should ensure that the transfer of funds resulting from company payments is complemented by improvements in project management by local authorities.

When considering the synergy of RP6 and RP7 [16], together with John Locke's reflections on the characteristics that a constituted government should have for the preservation of property [55], the argument that polycentric governance improves with the participation of stakeholders through the strengthening of their organizational capabilities††, knowledge about the SES, a culture based on constant learning and the reformulation of strategies according to a dynamic context is reinforced. It is in this context that the best results are obtained, in democratic spaces, when the relations between the State, mining companies and communities reach an optimum level of maturity for the collective approach to the challenges intrinsic to the SES.

Constantino [56], drawing on the thought of David Hume, points out that "established institutions contribute to determine the success of a society, and a republic can be wisely governed depending more on the difference in the forms that regulate men than on the character or education of those men". While it is true that institutions - understood as norms or rules - are an important factor for the results obtained in SES over time, the management of institutions (design and application) is determined by the degree of wisdom of those who influence society.

Now, based on the principles of design and resilience analyzed, the optimal management of SES in relation to large-scale mining in Peru is "in development", because there is still a gap in terms of regulatory quality‡‡, so this challenge should be taken up by strengthening the organizational capabilities between the three stakeholders (synergy between RP6 and RP7). For example, the Covid-19 pandemic brought about changes in solid waste management, incorporating the management of biocontaminated waste, more training focused on human rights and the management of their claims, the measurement of GHG and indicators linked to water. Therefore, organizational capabilities represent a key element in the internal management of mining companies, and a chance for the strengthening of organizational capabilities at the level of the three stakeholders, which will influence the results of the optimal management of SES in relation to large-scale mining in Peru.

5 Conclusions

Communities and companies are organizations, being constituted by people, resources and social and ecosystemic interrelations, through which matter, energy, and information flow, in order for such organizations to be functional and achieve their respective objectives. The set of characteristics that the regulations governing the use of resources in any organization

[††] Defined as the collective way of solving problems, which evolve over time through learning and demonstrate a dynamic component, also demonstrate a distinctive and superior way of combining and allocating resources [57].
[‡‡] In 2022, Peru ranked 49th out of 62 jurisdictions evaluated regarding the investor perception index of mining policies [58].

should have, form the theoretical framework of the design principles, which in this research has been applied to large-scale mining.

In this sense, the proposed methodology offers an alternative where the normative aspect of the use of resources (design principles) and the adaptive strategies that respond to disturbances and continuous changes (resilience principles) constitute the pillars that strengthen organizational capabilities. In future research, could consider with this methodological proposal, how the collective mindset affects organizational capabilities through the normative aspect and adaptive strategies. Together, they allow analyzing the responses to living in a state of constant adaptation and benefiting from the changes of the SES, and for which it is necessary to strengthen one of the factors that could be determinant for sustainability, such as organizational capabilities. It is important this type of research where links are formed between the methodological contributions of the DP and RP, which integrated with the ICMM principles, achieves a wide view that guides the optimal management of the SES, and which is useful to reinforce the holistic approach among the information disseminated in the sustainability reports.

Based on the design and resilience principles analyzed together with those of the ICMM principles, the optimal management of SES in relation to large-scale mining in Peru is "in development", with partial compliance with the multiple criteria, and the role of state entities is key to generate scenarios of stability that allow improving the management of SES over time, from which community organizational capabilities can also be strengthened.

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