European Research Studies Journal
Volume XXVI, Issue 1, 2023

pp. 230-246

Sustainable Management Applied to the Metallic Mining Industry in Mexico: A Conceptual Model

Submitted 20/01/23, 1st revision 10/02/23, 2nd revision 22/02/23, accepted 15/03/23

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Abstract:

Purpose: *The metallurgical industry is an important branch of the global economy. The activities of this industry cause ecological and social problems in Mexico. It is proposed to elaborate and verify a conceptual model of sustainable management for Mexican Metallic Mining Industry. Due to economic and environmental importance of this industry, the use of adequate conceptual model of management is of crucial importance. Hence the conceptual model is proposed.*
Design/methodology/approach*: Methodology contemplates an investigation of sustainability inside of environmental management in Metallic Mining Industry in Mexico. The bibliographical and theoretical information and assumptions allowed to design a conceptual model. The model has been validated by a case study, based on the holistic single-case study. The applied methodology consists of four steps: data acquisition and analysis, design, and qualitative verification of the conceptual model, conclusion elaboration and the initial draft of the best practice proposal.*
Findings: *The scope and level of implementation of selected parameters of environment protection specified by Mexican and international law in the field, and indirectly by analyzing the use of procedures recommended by the conceptual model, have been defined. The conceptual model was subjected to the positive valuation of experts from the mining industry in Mexico. The proposed conceptual model of sustainable management joins the UN Universal Principles of Sustainable Management with Mexican legislative parameters.*
Originality/value*: The originality of this study relies on the proposal of new conceptual sustainable management model for the mining industry in Mexico. Until now foreign models of sustainability have been mostly used for different internal areas. Mexico needs a strategy of aligning business management needs with the urgent implementation of the Environmental Agenda for the mining industry in Mexico. The model and results of its pilot implementation in the metal mining sector of San Luis Potosí State create the foundation for strategy definition and implementation. Final recommendation extends a possibility model to be applied in non-metallic and metallurgy sector.*
Keywords:
JEL codes:
Paper Type: *Research Paper.*

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1. Introduction

Mining industry activities generated a lot of negative consequences dealing with the impact caused to the environment (Martinez, 2022). Mining industry is an integrated activity: the extracted mineral resources require an industrial transformation to enable them to be used for the satisfaction of diverse needs. In consequence, it has become Mining-Metallurgical Industry (Saavedra and Sánchez, 2007).

The stages of the mining-metallurgical process are: (1) Exploration: the areas of interest are recognized, to confirm the physical and chemical characteristics that show that mineral deposits exist. (2) Exploitation: works designed to prepare and develop the area where there are mineral deposits, as well as activities aimed at extracting said minerals or substances from nature. (3) Concentration of minerals (metallurgy): works of preparation and treatment, smelting and refining of extracted mineral products, with the purpose of recovering minerals and substances in terms of purity (separation); (4) Closing: once the mining-metallurgical operation ends, the closure must be planned strategically, with the vision of reintegrating the property used to its natural or urban environment (CGM, 2014).

Each part of the mining-metallurgical process has a different magnitude of environmental risk during its execution. Environmental hazards formed the basis for the elaboration in the Agenda 2030 (UN, 2016) the Sustainable Development Objectives (SDG's), which in their definitions included economic, social and environmental aspects suggested to be implemented by UN member countries.

Mexico is identified in the world as an important nation that produces a large amount of minerals that contribute to economic mobility. Mexico produces 53 different minerals, which consist of 11 metallic minerals and 42 non-metallic minerals. Around 70% of Mexico's territorial extension has favorable geological features that allow the development of mining projects; this makes it one of the most important mineral-producing countries (Subsecretaría de Minería, 2017). Mining-metallurgical industry causes increases in the investment of foreign capital, productivity, exports, and employment (CAMIMEX, 2018).

However, it makes, as has already been mentioned, serious dangers for the environment. Mexican mining environmental laws (1985) attempt to specify environmental requirements at each stage of the production; however, Mexico still is one of the most backward countries in this context. Mexican Ministry of Promotion and Environmental Regulation oversees regulating this industry's environmental impact by promoting an optimal environmental care. These regulations have been published in such official documents as: Environmental Impact Manifests and Evaluation of Environmental Impact (SEMARNAT, 2012).

The objective of this paper is to present the conceptual model of sustainable management and its validation process. The model has been developed based on the

extensive study of solutions and requirements used in Mexican Metallic Mining Industry (Martinez, 2022). The results of the study allowed the selection of the SDG's and Legislative Parameters used to build the model. The results of the study have been evaluated by experts from mining industry in San Luis Potosi (SLP). They found the results of the study useful for the case of SLP and Mexican Metallic Mining Industry conditions in general (Martinez ,2022). The paper also includes the analysis of the environmental practices carried in the silver underground mine in Mexican State of San Luis Potosi (case study).

In this paper authors present: methodology, the importance of metal- mining industry for the economy of Mexico, the conceptual model, its application in the case of a selected unit in the state of San Luis Potosi, conclusions and best practices proposal.

2. Research Methodology

The research works have been deployed over the years 2019-2021 and described in the work "Sustainable Management Model applied to the Metallic Mining Industry in Mexico: Case study in San Luis Potosi" (Martinez, 2022). The research was thematically focused on the issue of sustainability inside environmental management in metallic mining industry in Mexico. The research provided the basis for the selection of SDG's and legislative parameters according to the characteristics of the Mexican metallic mining industry. The bibliographical and theoretical information and assumptions obtained and analyzed in the paper have been validated by a case study. Methodology consists of the following parts (Figure 1):

1. Data acquisition and analysis
2. Design of a sustainable management conceptual model
3. Qualitative verification of the conceptual model

Data acquisition included analysis of the results of different studies and innovation projects in the mining industry. Selected national and international documents, programs and models related to the environment have been analyzed (Martinez, Bednarek, and Zulawska, 2020). The results of the analysis have served two purposes:

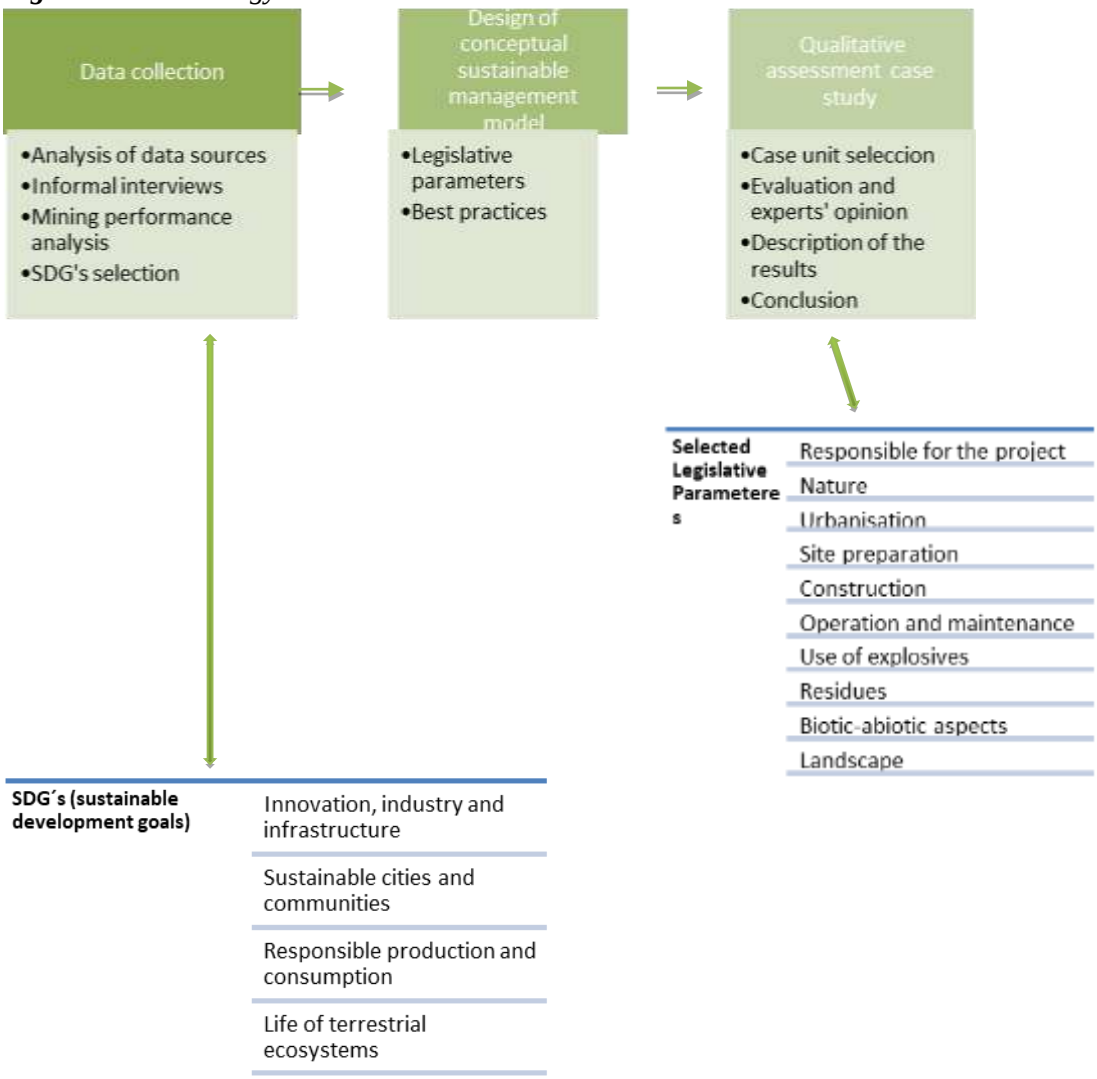
- design of the Sustainable Management conceptual model;
- development of the scope of the validation of the conceptual model during the activities of the case study (Martinez, 2022).

The model should be verified in two different ways:

- qualitative validation
- quantitative validation.

The paper presents only qualitative validation results. Quantitative validation is recommended to be developed in further research.

Figure 1. *Methodology Elements*



Source: *Authors' elaboration based on UN (2016) and SEMARNAT (2002).*

The case study has been developed to analyze different research items in the same silver mine. It was possible to verify a theoretical description of the proposal of sustainable management conceptual model and objectives of research (Yin, 1994: 2002). The case study has been conducted in a metallic mineral underground mine that produces silver located in the State of San Luis Potosi. The case study unit selection was for the sake of convenience (Hernandez, 2014). The selection also

considered the geographic location of the mine, the mineral being mined and the importance of the State of San Luis Potosi in the Mexican economy (see: The importance of Metallic Mining Industry in Mexico).

The State of San Luis Potosi represents 3.12% of the Mexican territory and has 91% mineralized soil (SGM, 2018). Mineralization and geographic location promote it as an economically active state by attracting 5.9% of foreign investment in mining. The state ranks 1st place in the country in the production of Fluorite (and second in the world), 3rd place in Zinc and Copper production, 5th in Gold and 8th in Silver, data that place San Luis Potosi as the fifth state in Mexico in its mining production (BANCOMEXT, 2018). The San Luis mine has been adopted as a representative case for Mexican Metallic Mining Industry (Martinez, 2022; Martinez, Bednarek, and Zulawska, 2020).

The case study started from the evaluation of environmental practices of a mine meeting the requirements of Sustainable Principles taken from the Agenda 2030 (UN, 2016) and Legislative Parameters from the Environmental Impact Manifest (SEMARNAT, 2002). The official documents to follow and evaluate the environmental practices in Mexico. The case study fulfills the following objectives:

1. performed analyses related to the foundations of sustainability and legislation for Mexican Mining Industry;
2. defined recommendations for the Mexican Metallic Mining Industry.

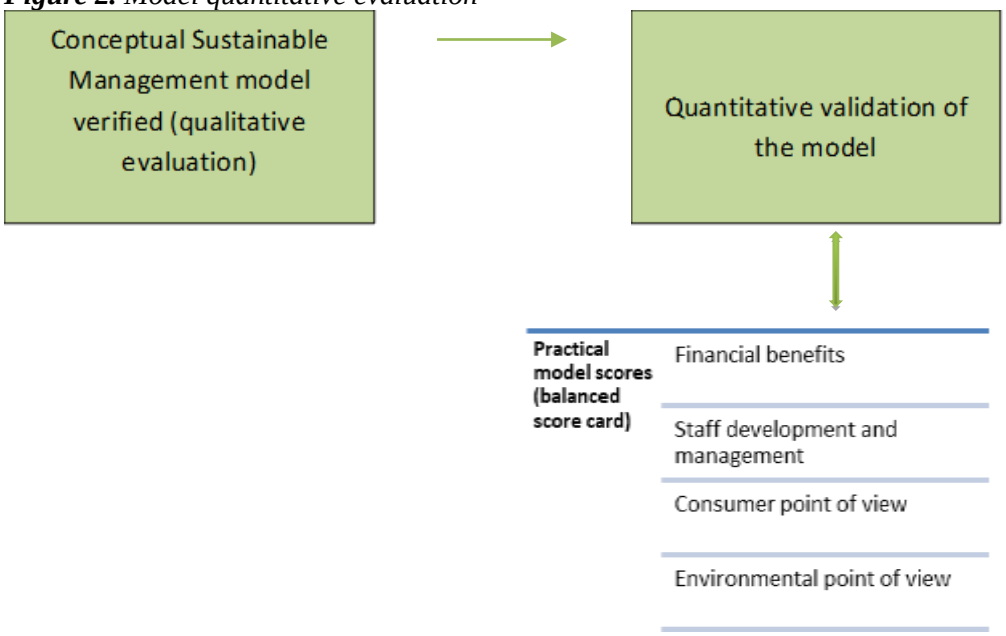
Paper recommends, among other things, further conceptual model implementation through day-to-day activities in different type of Mexican enterprises. The description of the application results will provide feedback to develop the best practices to implement in Mexican Metallic Mining Industry (Figure 2).

3. The Importance of Metallic Mining Industry in Mexico

The Metallic Mining Industry has a strong economic contribution in Mexico. 70% of the national territory contains mineral deposits and has a high potential for mining developments. Mexico is located among the 12 main producers worldwide, which places it as the first destination for investment in mining exploration in Latin America and the fourth in the world (SE, 2019; SNL Metals and Mining, 2019; SGM, 2019).

Mining industry belongs to six main strategic sectors of the country by capitalizing 4% of the national GDP and attracting 5.1% of foreign investment in mining. 34.89% of the economically active population belongs to Mining Industry directly and indirectly. The wages of workers are 32% higher than the national average (INEGI, 2018; SGM, 2019).

Figure 2. *Model quantitative evaluation*



Source: *Authors' elaboration based on Kaplan and Norton (1992).*

Metallic Mining Industry represents the 50.38% of the total of mining production in the country with the 10.25% of silver production. For several years Mexico has been the main producer of silver in the world (SE-SGM, 2017), exporting it in semi-manufactured form, in raw form, in metal plating and powder (SE-CGM, 2017). Silver keeps Mexico as the main seller of jewelry and silverware in the world. The main silver-producing states in Mexico are Zacatecas, Durango and Chihuahua; extraction and processing are also concentrated in Coahuila, Guanajuato, Guerrero, Hidalgo, Jalisco, the State of Mexico, Querétaro, Sinaloa, Sonora and San Luis Potosí (Clausell, 2010).

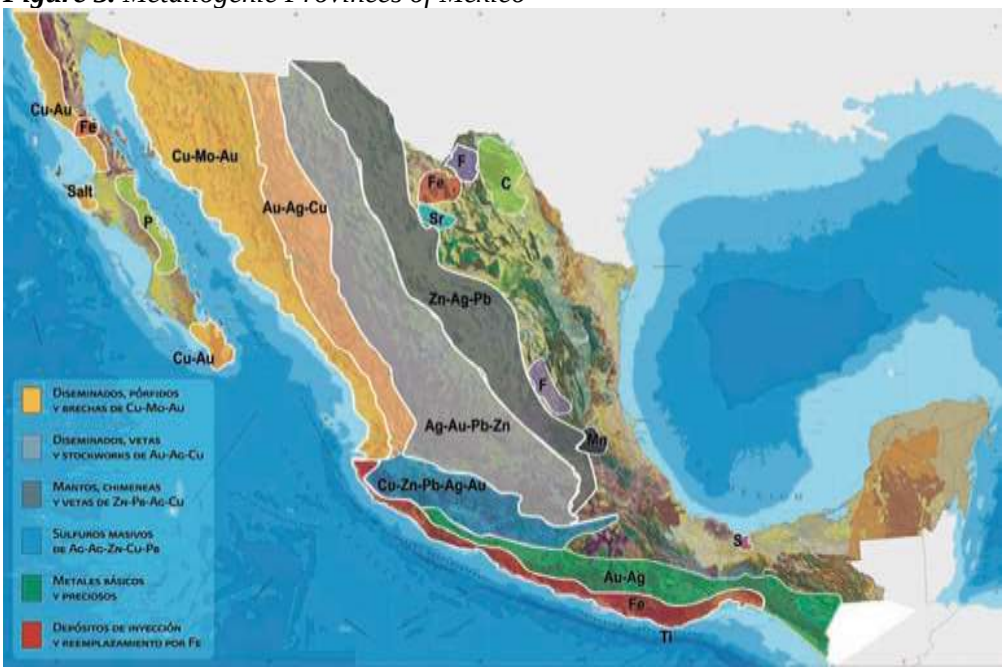
The environment, centralized around the mining industry in Mexico, is one of the most backward in this context. To give an example, San Luis Potosí is considered by the Ministry of the Environment and Natural Resources (SEMARNAT) as the most polluted entity, out of a list of 27 states, as revealed in research carried out last July.

The report indicates that 46 polluting sources operate in San Luis Potosí territory (https://www.google.com/urlsa 28.11.2022). It means that importance and relevance of carrying out a research within the Mexican mining metal sector is very important and provides information about the implementation of these SDG's.

Mining activity generates substantial changes in the land, modifications of the geological structure and following exploitation may destruct both, surface and

underground water resources. Biological environment can be partially or completely destroyed during mining operations (Arranz, 2015). In Mexico (SEMARNAT, 2016) describes the possible impacts, the orography, flora and fauna, in addition to generating dust and particles and during explosions.

Figure 3. *Metallogenic Provinces of Mexico*



Legends:

** Scattered, Porphyry & Breccias of Cu-Mo-Au*
** Disseminated, Veins, Stockworks. Of Au-Ag-Cu*
** Strata, Chimneys, Veins of Zn-Pa-Ag-Cu*
** Massive Sulphur's, Ag-Zn-Cu-Pa*
** Basic and precious metals*
** Injection and Replacement Deposits of Fe*

Source: *Servicio Geológico Mexicano (Mexican Geological Service, SGM, 2017).*

Underground mine vents emit solid particles containing metals; liquid emissions of waste, there are also remains of compounds due to the use of reagents and/or inputs in the extraction and beneficiation process. In this situation, research on sustainable management conceptual models seems to be of great importance.

4. Conceptual Sustainable Management Model

The conceptual model (Figure 4) covers the four production elements of the metal industry, exploration, exploitation, benefit and closing (Martinez, 2022). All elements have a different magnitude of environmental risk. The different definitions of these parts are very often confused and are published by national mining

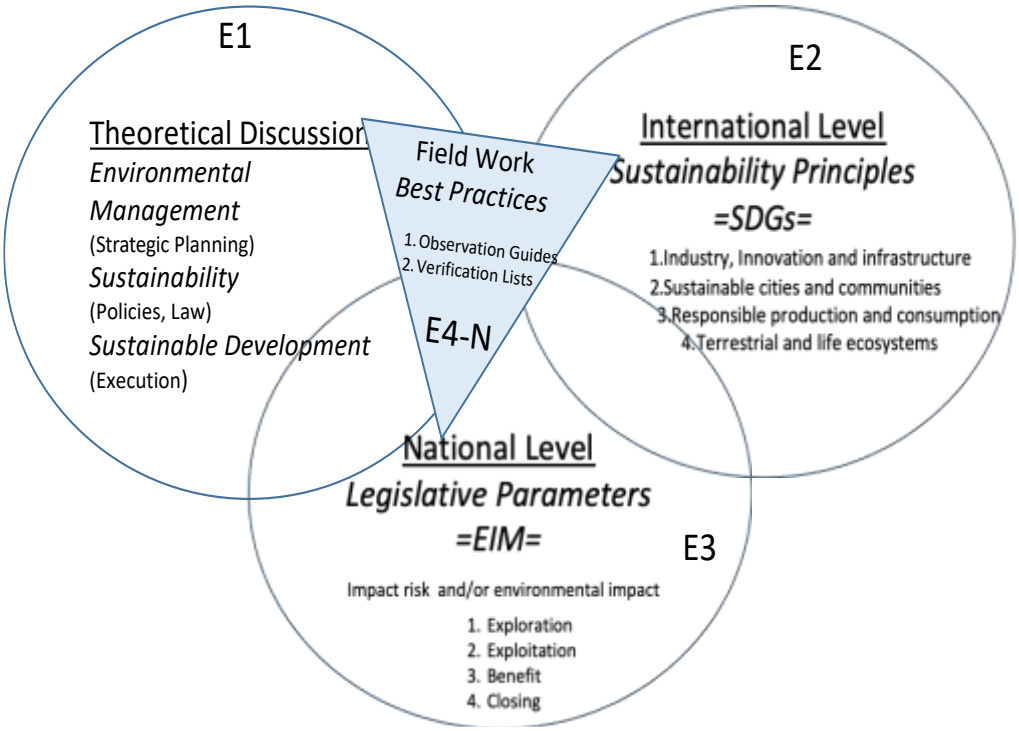
companies (ANM, 2000; INACAP, 2001; CFI-GBM, 2007; ELAW, 2010) affecting the community's perception of importance of mining activities.

The article adopts definitions according to (CGM, 2014). It was recognized that the definitional diversity requires the development of the model of sustainable management, which will propose, according to the results of the study, the legal, social, and operational duties of these mining-metallurgical Mexican units. The conceptual model (Martinez, 2022; Martínez, Bednarek, and Zulawska, 2020) of Sustainable Management of the Mining and Metal Industry is based on three elements:

- theoretical foundations derived from Environmental Management - E1
- international SDG's included in the 2030 Agenda for Sustainable Development - E2
- Mexico's national legislation on environmental parameters summarized in the Environmental Impact Manifesto - E3.

The three elements allow to define and assess the application of best practices for mining sustainable management - E4.

Figure 4. *Conceptual Sustainable Management Model*



Source: *Authors' elaboration.*

Environmental Management (EM), e.g., social factors and its relationship with environmental law, has been discussed in different bibliographic sources, (Bonnicksen and Lee, 1982). Colby (1991) described paradigms of the relationship of the human being with nature, such as: frontier economy, deep ecology, environmental protection, and resources. Massolo (2015) has described EM as the set of actions and strategies that organize the environment achieving quality of human life as a result.

Pigretti (2004) affirms that the companies with vision of future consider the EM as an opportunity to reduce the consumption of raw materials in their activities, processes, and services. Díaz (2015) describes EM as the set of strategies, including internal ones, and legislative policies allowing a continuous improvement of the processes by implementation of best practices to avoid or minimize the environmental impacts. EM includes sustainability and its development.

The paper "Sustainable Management Model applied to the Metallic Mining Industry in Mexico: Case study in San Luis Potosi" (Martinez, 2022) defines the elements that allow for a detailed assessment of the implementation of the SDG's at mines. It was also determined which parameters of Mexican legislation were included in the presented model. This is presented in the following Tables 1 and 2.

Table 1. *Elements to identify environmental impact risks for underground mine production sector according to SDG (Martinez, 2022).*

Industry, innovation and infrastructure.	**Sustainable cities and communities**
1. Construction of roads for exploration machinery. **2.** Maintenance of equipment in the field **3.** Displacement of material in open pit and underground locations. **4.** Use and containment of chemical reagents. **5.** Water contamination. **6.** Incomplete supervisions.	1. Construction of roads and steps without considering populations. 2. Use of explosives without earlier technical studies. 3. Limited economic resources – no community support.
Responsible production and consumption	**Functioning of terrestrial ecosystem**
1. Displacement of material by exploration site. 2. Play groundwater level. 3. Construction of underground mine shots. 4. Construction of under no-goers. 5. Extraction of gases into the atmosphere. 6. Storage of obsolete reagents in profit plant and laboratories.	**1.** Road construction. **2.** Use of oils. **3.** Earth formation. **4.** Construction of ships: infrastructure. **5.** Insufficient or no economic programming for closing and remediation stages.

Source: *Authors' elaboration.*

Table 2. *The following Legislative Parameters have been included in the conceptual model (Martinez, 2022).*

• Working lifetime
• Responsible for the project
• Nature
• Dimensions
• Use of land
• Urbanisation
• Site preparation
• Construction
• Operation and maintenance
• Use of explosives
• Residues
• Biotic-abiotic aspects
• Landscape

Source: *Authors' elaboration based on UN (2016) and SEMARNAT (2002).*

Sustainable development requires the identification and application of various methods and practices that ensure this development. They are selected individually for each analyzed enterprise. Their precise definition is possible only after quantitative evaluation of the model. For example, if it were recommended to change the numerical values expressed through the parameter operations and maintenance (see Table 2: operations and maintenance) it would probably be possible using Lean methods.

6. Case Study: Metallic Underground Mine Description

Case unit: The case study unit is located in the part that runs through the state of San Luis Potosí and Zacatecas. San Luis Potosí is a state that has arid and semi-arid areas, and has a landscape characterized by rocks, deep canyons, mountains and plains (Martínez, Bednarek, and Zulawska, 2020). The State contains, in more than 90% of its extension, metallic and non-metallic minerals. The underground mines are typical for state's and Mexico's mining industry (SGM, 2018). The case unit is the part of ASI corporate, of Canadian origin, it is the mine, which extracts silver ore (Ag) as the main metallic concentrate and lead (Pb), as a secondary one.

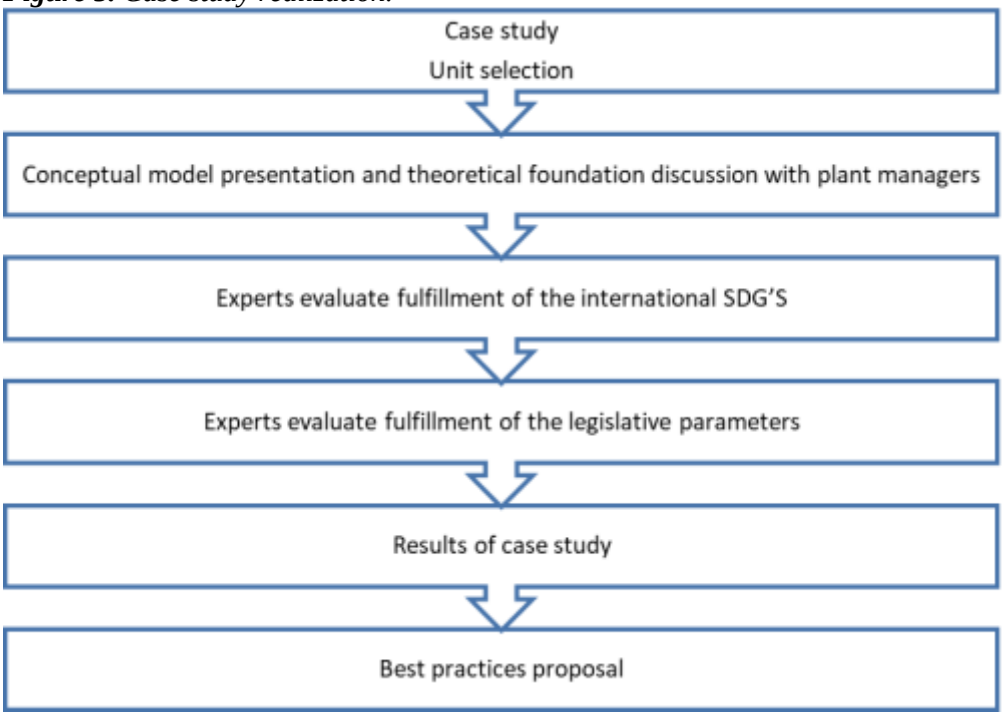
The basic process includes the separation of silver and lead ore from others, through grinding, qualification and flotation (SE, 2019). The mine activities are very important because Mexico is the first producer of silver worldwide, according to the data from Mineral Commodity Summaries (2017); San Luis Potosí participates with 3.3% of the national metal production. The case unit, being an underground mine, presents a typical mine design, where with using of explosives, it is possible to create access to the veins that contain minerals with high economic value.

Many authors demonize these blasting activities as ones leading to the destruction of fragile landscapes, generation of environmental disturbance and destruction of the way of life in order to accumulate benefited material for other industries (Muradian and Alier, 2002; Bebbington, 2009; Downey, Bonds, and Clark, 2010). The case unit is an underground mine with narrow accesses, medium ventilation and notable water leaks. The staff turnover indicator is very high at all employee levels. The mine has a lot of different administrative problems and does not carry out important projects in an operational, social and especially environmental function.

But, on the other hand, mining activity has contributed to the founding, establishment and economic growth of San Luis Potosí region. These activities incorporate several dimensions: political, social, cultural, and environmental. Foreign investment in this industry is not common in Mexico and in this State.

The case unit has been in charge of several transnational mining companies acquiring the rights to exploit the mine, in an excessive way due to the lack of legal limits, extracting the mineral resource in an irrational way, obtaining high economic benefit and generating social discontent due to environmental impact (Sánchez, 2014). The case study has been realized according to the diagram presented below:

Figure 5. *Case study realization.*



Source: *Authors' elaboration.*

6.1 Some Results of the Case Study

The results of the case study are presented following the above diagram and with the definitions of selected international SDG's, provided by SDG-Tracker and Mexican Legislative Parameters.

6.1.1 International SDG's

1) Industry, innovation and infrastructure. It means orientation of the case unit to resilient infrastructure, promotion of sustainable industrialization and fostering innovation. During the case study it has been observed that plant activities do not fullfil these international SDG's.

2) Sustainable cities and communities means making cities inclusive, safe, resilient and sustainable. During the case study it has been observed that a lot of plant activities do not fullfil these international SDG's, for example:

the plant has not any monitoring system of gases at the installation sites of mine extractors, as well as automatic dispensers of reagents. Air quality measurements are made manually by employees;
the dumps of sterile material are located in unprotected areas;
the mine surface exploration activities are being carried out all the time;
the project of tailings dam started months ago and has not be evaluated until now.

3) Responsible prodution and consumption means consumption and production on the bases of resource and energy efficiency, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all. During the case study it has been observed that few and only selected plant activities fullfil these international SDG's:

the design of the dam of the conventional type allowing that material to be removed from the basin could be used as loan material for the construction of the bank. It avoids the possibility of additional negative environmental impact;
the definition of the environmental impact studies include the information about records of delivery and results of monitoring and evaluation activities of the corresponding authority. In the case of unmeasured environmental impacts the emergency plan has been prepared. This plan was endorsed by the experts' and the company's technical manager, who are responsible for the selection of a trained team for impact studies implementation;
ventilation system inside the mine has been redesigned and rebuilt with the delivery of new shelters for personal rescue. The plant started to modernize its roads and emergency exits (ramps, counter holes);
the mine uses the water and chemical neutralizers on leaching terraces;

the case unit has a pumping system and the indicators of chemical contamination of the water predominantly remaining within the prescribed limits;
the plant considered creation of a post-flotation dam and the reforestation of outskirts of the mine.

4) Terrestrial and life ecosystem means sustainably management of forests, fighting desertification, halting and reversing land degradation, halting biodiversity loss. During the case study it has been observed that plant activities do not fullfil these international SDG's.

6.1.2 Legislative Parameters

Mexican Legislative Parameters have been included in the conceptual model. During the implementation of the case study, the relationship between SDG's, Legislative Parameters and productive stages of Mining Industry was defined (Table 3). Until then, the relationship between these elements had not been defined. Each was defined in a different set of local and international documents. This made it difficult to analyze, classify or quantify them. These relations could be used to evaluate of fulfillment of the parameters in different operations of mining industry.

Table 3. *Sustainable Principles, Legislative Parameters vs. productive stages of the Metallic Mining Industry*

	Industry, innovation and infrastructure				Sustainable cities and communities				Responsible production and consumption				Terrestrial and life ecosystem			
	EP	EX	BF	CL	EP	EX	BF	CL	EP	EX	BF	CL	EP	EX	BF	CL
Working lifetime					x											
Responsible for project				x				x				x				x
Project nature		x								x	x	x		x	x	
Dimensions		x		x		x	x	x		x	x	x			x	x
Use of land	X	x	x	x	x	x	x	x		x		x	x	x	x	x
Area urbanization	X	x	x	x		x		x		x	x	x		x	x	x
Site preparation	X				x						x	x				x
Construction		x	x					x		x	x	x	x	x	x	
Operation and maintenance		x	x	x	x			x		x	x	x		x	x	x
Abandonment				x				x				x				x
Use of explosives		x				x				x				x		
Residues		x	x	x		x	x	x		x	x	x		x	x	x
Infrastructure for residues				x				x			x	x			x	x

Abiotic aspects					x			x		x	x			x		x
Biotic aspects					x			x								
Landscape		x	x	x		x	x	x				x		x	x	x

Note: *EP-exploration; EX-exploitation; BF-benefit; CL-closing. Source : Authors' elaboration*

6.1.3 Particular Comments on the Metallic Underground Mine Case Study

Canadian capital is involved in the mine, which, due to external controls (shares listed on the stock exchange) and ensures compliance with higher environmental standards. The mine administration has worked out the project "Environmental Impact Manifesto", approved by the relevant state authorities. The mine plant elaborated study of evidence of devastation that should facilitate risk measurement.

The current administration has financial resources to prevent negative effects on the environment. On the other side, the documents poorly describe how to neutralize the dam. The mine was a place of social riots. The local habitants have demanded compensation for the destruction of some places of their villages as a result of the use of explosives. The protests of the habitants are now strictly controlled by the authorities (SEDENA). The gap between the studies and the documents elaborated and implemented by mine administration and expectation of the local residents has been observed.

7. The Best Practices Proposal – Initial Draft

Following the discussed procedure, during the validation of the described model, the proposal of good practices can be developed only after the quantitative validation of the model. This will allow to develop a general proposal for the application of selected methods, estimating their costs and expected effects. During the case study there was Gemba Walk organized where the group of experts discussed the possible practices that could be applied to improve the performance of the plant. Visual inspection session has been organized. The experts have concluded that the mine has problems with:

- its maintenance system,
- job and logistic organization lack
- efficiency in its processes
- application of problem-solving methods

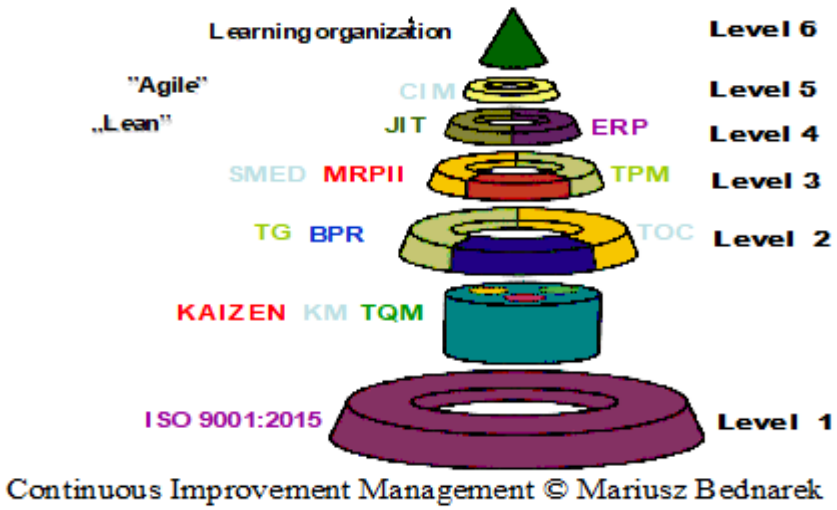
Mining staff could identify places in processes where undesirable effects appear. It was observed that at the mining plant:

- the root problems are almost never immediately perceived
- managers manifest themselves through undesirable effects linked to a chain of cause and effect

- the elimination of an undesirable effect provides a temporary and insecure solution.

Considering the experience in solving the problems of losses in production processes in many companies in South American countries (Bednarek, 2017), it was found that mines can be recommended the components of Lean Manufacturing methods. Lean Manufacturing is represented, as the idea of Continuous Improvement Management in the following Figure 5.

Figure 5. *Continuous Improvement Management*



Source: *Own elaboration.*

8. Conclusions

1) The Metal Mining Industry in Mexico is particularly important for the Mexican economy. Silver is a highly sold mineral and that is why several States try to develop mining activities in lands rich in silver veins. The mining industry generates environmental problems in Mexico by contaminating water, land, and air. Management and environmental culture must be developed not only in diverse types of industry, but in Mexican society as well.
2) In Mexico there are different regulations related to environmental protection prepared by the government (Legislative Parameters) as well as on the business level. The regulations exist, but their practical application leaves much to be desired. Regulations very often formulate theoretical protection

requirements without saying what to do to implement environmental management practically in a comprehensive way.

3) The conceptual model presented in this paper due to its integrated design could complement the regulations, evaluating the level of progress in the application of environmental protection requirements in a company and defining the topics to be implemented.
4) The model joins together both the legislative principles for Mexican environmental management and the Sustainable Development Goals (SDG's) defined in ONU documents. This allows us to say that the model is a result of an integral design and therefore its application in diverse types of mining is recommended.
5) It is recommended to continue the implementations of the model in the mining of non-metallic sectors and in refineries to adjust in detail definitions of SDG's to the protection of the environment in Mexico.
6) Continuation of implementations of the model in diverse types of Mexican mining companies will also facilitate an analysis of compliance of Mexican legislative principles with the international SDG's.
7) Continuation of implementations of the model in diverse types of Mexican mining will facilitate its quantitative evaluation that allow to define as a numerical factor the minimum levels of compliance with environmental protection requirements. The results of evaluation make it possible to work out a detail definition of the best practice for improving of mining critical processes.
8) Continuation of implementations will help in continuous improvement of the model.

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