Environmental Management and Sustainable Development
ISSN 2164-7682
2018, Vol. 7, No. 2

Dynamic Matrix for an Adaptive Environment Management in Mining: A *Feed*-engineering Alternative?

S. B. Mondoukpè Lagnika
École de technologie supérieure, Canada

Robert Hausler
Department of construction engineering, École de technologie supérieure, Canada

Mathias Glaus
Department of construction engineering, École de technologie supérieure, Canada

Received: March 30, 2018 Accepted: April 23, 2018 Published: May 18, 2018
doi:10.5296/emsd.v7i2.12894 URL: https://doi.org/10.5296/emsd.v7i2.12894

Abstract

Environment impacts are usually determined by quantification or an evaluation system derived from several methodologies including environmental assessment, matrices, and data cross-referencing. This study uses a dataset obtained from validated mining Environmental Impact Assessments (EIAs), some monitoring reports and scientific insights on open-pit mines (OPM). The purpose here is to build a dynamic matrix system over time to facilitate a systemic evaluation of environmental impacts and to find in-depth preventive measures in any OPM. The four dynamic matrices are built with qualitative and numerical values in both magnitude and significance terms. As one of the issues is to minimize negative risks in OPMs, one outcome points out the environmental factors of mining operations sensitive to the variations over time and the variability of the parameters themselves. The results show secondly that the data (qualitative and quantitative) vary from EIA stage to a post EIA status like activities or environmental factors numbers. Thirdly, the impact of activities on each part of environment components and the incidence of all activities during the mines' life cycle is easier to identify whatever the data density. In the fourth line, this paper indicates that the dynamic matrix in an optimal alternative in the process of determining preventive measures to mitigate the risks and the need for an interactive environmental follow-up program in mining or similar industry. This approach reduces the following-up monitoring weaknesses and allows managers, as a multi-criterion decision-making approach, to take enlightened actions.

Keywords: Environmental monitoring, EIA, Matrix, Assessment, Over time, Risks, Open-pit, Follow-up program

1. Introduction and Scope of Study

Environmental assessment is an innovative tool that has revolutionized anthropogenic impacts on the environment and has improved since the Rio conference (Lagnika, 2009). Born in the 1970s, environmental assessment was established first to satisfy growing public concerns on our ecosystem but also to pursue and better develop industrial activities (Bouvier, 2006; Gorova, Pavlychenko, Borysovs'ka, & Krups'ka, 2013). In order to reduce, regulate, control or adjust environmental risks arising from human activities, environmental impact assessment (EIA) is the best known tool to date before implementing any industrial projects (Evangelinos, Allan, Jones, & Nikolaou, 2014). EIA, for its part, is a crucial internal step in any project involving negative impacts on the ecosystem where it must be implemented. In turn, EIA consists of two phases that best ensure the identification of risks: (1) corresponding mitigation measures and (2) monitoring of activities from construction to the end of industrial activities. Among all the industries, mining is the one who afflicts the whole environmental factors (geomorphic, soil, atmospheric, water, acoustical, social, vegetal, wildlife, financial and so on) (Chinbat, 2011; Pokhrel & Dubey, 2013). Lagnika, Hausler, and Glaus (2017) and many other authors highlighted numerous risks associated with operation mining on the surrounding environment where the industry is based. In Canada and in Quebec, there are different impact assessment procedures by region, but in most of the cases, a mine exceeding 7000 Tons of minerals is subject not only to the EIA but also to a public hearing. These procedures are supposed to help managers to develop and operate their mining project in an environmentally responsible and safe manner at all levels for the benefit of communities and stakeholders. However, the observed data of EIA procedures under environment Act of Gouvernement du Canada (2017), environment quality Act of Gouvernement du Québec (2017a) and sustainable development Act Gouvernement du Québec (2017b) regulation respecting the review shown in figure 1, form a sufficient composition which can enable a good management.

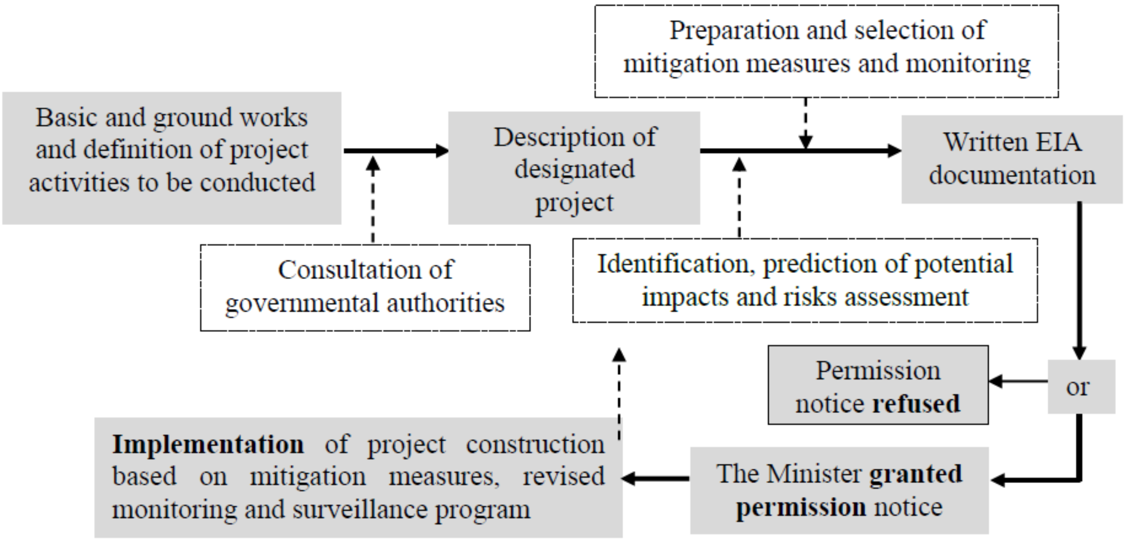


Figure 1. EIA regulation respecting Canada and Quebec laws. An adaptation of Canter (1982)

The procedure takes into account: the purpose of the project, the environmental effects of the mine preparation, their scope, the significance of the effects mentioned, public comments (public hearing), mitigation measures including feasible alternatives, the follow-up program, and monitoring. But, despite the effectiveness of EIA, there are still problems that disrupt the ecosystems once mines are put into operation. Some collapses or failures of dams occurred over the world are registered: a coal mine at Saunders (USA, 1972), in Stava (Italy, 1985), in Spain (1998), in Sweden (2000) and in an aluminium mine at Kolontar (Hungary, 2010). Also, authors notice significant pollution and environmental degradation around extraction operations and production processes (Křībeka, De Vivob, & Davies, 2014; Singh, Ihlenfeld, Oates, Plant, & Voulvoulis, 2011). Others do not hesitate to expose the impacts of unbalancing incidences on basic human need as loss of soil fertility, air contamination by dust, health and safety issues, acidification of wastewater, destabilization of: groundwater, wildlife, geomorphology, etc. (Agbo & Honkpehedji, 2009; Lagnika et al., 2017).

These are the reason why authors like Bouvier (2006) still consider that the potential of impact assessment is not exploited. Indeed, earlier Duinker (1989) argues that the basic goal of reducing risks in predictions is to generate a temporal time series of surveillance data and verify them. Actually, the EIA procedure requires environmental monitoring at the project construction but, the realization of a follow-up program at the end of the activities does not allow enough time to observe the evolution of the risks between the two big phases (project phase and operation phase). Bibliographic research carried out during this work through six scientific databases (Emerald Insight, Wiley & son online, Engineering village, Google scholar, Taylor & Francis and IEEE Xplore) revealed very few articles on Leopold's matrix, multi-criterion assessment studies and the weighting of impacts on many activities like irrigated dam but none in mining. Few investigations carried out on this topic between 1982, 1989 and 2017 highlight the weaknesses of environmental follow-up, which is the centerpiece of the EIA. These precedents show the lack of studies or investigations made by practitioners or scientists to improve more the tool which is useful for human activities and ecology control. In view of this inevitable livelihood of uncertainties in our dynamic ecosystems, MacKinnon (2017), insists recently for an ongoing adaptive approach to following-up environmental impacts. To do so, temporal data have to be set before the project construction and while the mine is put into operation. Then, depending on the severity of each risk and the mitigating or aggravating factors, the measures have to be chosen appropriately in order to know precisely and remedies widely the actions responsible for the negative impacts. Later, the action plan should be determined or adapted under the incurred circumstances.

2. Research Methodology

The aim of this paper is to carry out a dynamic matrix system to facilitate a systemic evaluation of environmental impacts and to observe the variability into the risk parameters in any OPM. An analytical framework of the obtained data as shown in figure 2 describes it. The methodology process is an evolving cycle that can be distilled down to six stages. First, the problematic is identified. Secondly, the grid holds the information and criteria around specific inclusion and exclusion factors.

The inclusion factors are: "to be a mining organization that operates as an open-pit and to obtain the permission notice from the government’s. The exclusion factors are to be: "an underground mine or an open-pit mines (OPM) organization that has not yet obtained the permission notice/ an OPM that cannot produce more than 7,000 tons because this is not subject to EIA/ a proposed expansion and development of OPM or not/ an OPM with an incomplete EIA". Representative OPM data from the literature review and EIA that have been approved by the government, will serve as a basis for these numerical and qualitative analyses.

So, following the step of the selection of these factors, a technical review of the assessments, 11 EIA reports with public hearing reports shown in the Table 1, several scientific articles, technical reports, federal and provincial legislation were studied in depth. From those results, the environmental factors, the significance of the impacts according to the value of the environmental component (VEC) as well as the intensity with the extent, were determined and harmonized throughout this work. Then, the matrices were developed and later, a sensitivity analysis was done to compare the results from EIA step to the post-EIA step.

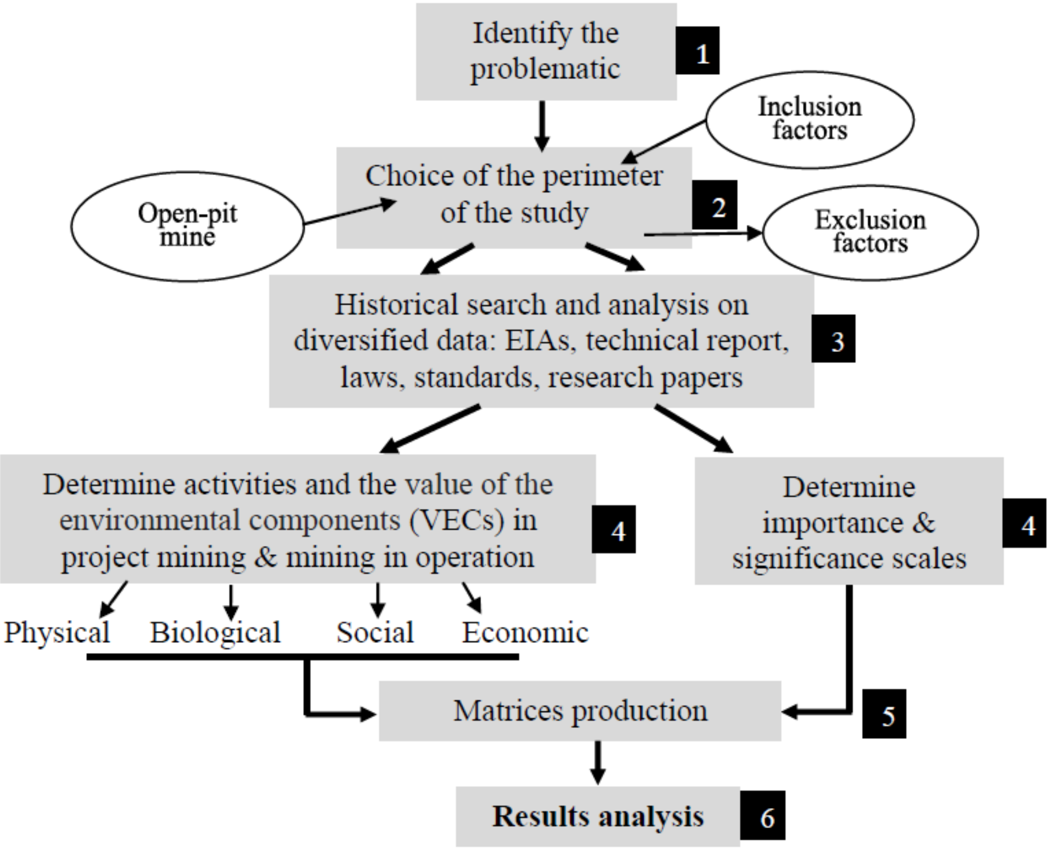


Figure 2. Description of the work methodology

Table 1. Summary of the EIA or public hearing reports studied

	EIA or Public hearing reports	**References**
1	Sisson mine project	New Brunswick (2015)
2	Apatite mine	BAPE (2013)
3	Coal mine	Alberta government (2012)
4	Kitsault Mine	Agence canadienne d'évaluation environnementale (2013); Amec Foster Wheeler (2012)
5	Akasaba west project mine	WSP Global (2015)
6	Whabouchi mine	Nemaska lithium and Agence canadienne d'évaluation environnementale (2013)
7	Beaver dam mine	Agence canadienne d'évaluation environnementale and Atlantique Gold Corporation (2017)
8	Niocan project mine	Roche ltée (2000)
9	Arnaud inc. project mine	Roche ltée (2012)
10	Apatite project mine in Paul lake	Genivar (2013)
11	Bloom Lake Iron Mine	Genivar (2006)

2.1 Study of Area

This work considered the review of 11 open pit mines across Canadian provinces summarized in the previous Table 1. It also took account of the inclusion and exclusion factors (previous section 2), with their approved public hearing reports and environmental compliance certificates.

2.2 EIA and Ni 43-101: What is the Difference?

The Canadian government designates a mine as any set of surface or underground infrastructure intended for the extraction of minerals (Gouvernement du Québec, 2011; Ministère du Développement durable de l'Environnement et des Parcs, 2012; Québec, 2017). This activity is subject to several laws, regulations, standards and requires any manager not only to submit an EIA but also a technical document that serves as a national instrument called Ni 43-101 (Autorité des marchés financiers, 2016). Ni 43-101 is a technical report that includes an all-round form, all material scientific, mineral-physical aspects and technical data concerning the mining project. It is about to provide specific details concerning mineral exploration, development, and production activities in a mining area by a qualified person. This technical report, which is intended for the investing public and its advisors, may contain information similar to what is used in an EIA, but it remains simplified on environmental issues of this activity. The reader should note that the Ni 43-101 reports have only been considered partially.

As the decisions or predictions must be made, it would, therefore, be wise to make an up-to-date assessment of the potential impacts on OPM and its operating parameters before continuing this study. Holling (1978), Rist, Felton, Samuelsson, Sandström, and Rosvall (2013) identified all the interactions of any ecosystem, the components and the uncertainties as obstacles to any adaptive management. Such a broad spectrum of impacts and risky situations because of problematics due to their complexity which are not always well or sufficiently understood in the available data.

2.3 Activities and the Value of the Environmental Component'S (Vecs) in Project Mining and Mining in Operation

The variables retained were: the mining activities from the project to the termination and the environmental factors considered in the literature consulted on OPMs. Table 1 and 2 provide a detailed list of environmental factors and mining operations at mining project status and once the mine is operational. These two categories of detailed lists confirm the dynamic temporal notion designated for the purpose of this research. But preliminary studies for the realization of matrices go beyond EIAs studied to get this detailed list. Indeed, the categorization performed required a historical search data on the environmental impacts of mining operations as well as the monitoring of the historical evolution of the EA in the industry. Then, this has resulted in a thorough consultation of the existing legislation and standards related to the activity. Also, the historical data from government bodies and BAPE registers help to shape, invalidate or confirm the existence of risk situations, impacts as well as the relevance of dynamic parameters to be considered and the extent of environmental damage caused. The environmental factors and sub-factors were collected from gray literature, scientific databases, available EIAs, few Ni 43-101, scientific articles, organizational or government documents, and other reports or briefs. The cause-and-effect relationships between actions and VECs have been studied through EIAs reports and in-depth reports to attain and recapitulate the impacts close to the ground situation.

Table 2. Summary of environmental factors or valued components of the environment (VEC)

VECs		STATUS	
		PROJECT	**REALIZED**
Geomorphology	Landscape	Morphology	Morphology
	Topography	Geography	Geography
Pedology	Ground	Quality of the soil resources	Quality of the soil resources
		Surface deposit	Surface deposit
	Subsoil	Geology	Geology
		Geotechnical conditions	Geotechnical conditions
		Sediments	Sediments
		Erosion	Erosion
		Sterile and residues	Sterile and residues
Atmostpheric	Air	Quality	Quality
		Pollution	Pollution
		Emission and deposition of dust	Emission and deposition of dust
	Climate	Microclimate	Microclimate at workstations
		Suspended particles	Microclimate
Acoustic	Noise	Level	Suspended particles
		Noise pollution	Level
	Vibration	Vibration level or air overpressures	Noise pollution
Vegetal	Flora	Species at risk	Vibration level or air overpressures
		Density and diversity	Species at risk
		Aquatic plants	Density and diversity
		Wet areas	Aquatic plants
Wildlife	Animals	Habitats	Wet areas
		Density and diversity	Habitats
	Aquatic species	Species at risk	Density and diversity
		Invasive species	Species at risk
	Mammals	Species at risk	Species at risk
		Most abundant species	Most abundant or common species
	Birdlife	Species at risk	Species at risk
		Most abundant species	Most abundant species
Water	Surface water	Morphology of waters	Invasive species
		Flow / Debit	Morphology of waters
		Level	Flow / Debit
		Sedimentary regime	Level
		Groundwater	Sedimentary regime

	Groundwater / Aquifers	Debit	Groundwater
		Quality	Debit
		Level	Quality
		Hydrogeological conditions	Level and infiltration
	Runoff waters	Erosion	Flood
		Effluent quality	Hydrogeological conditions
		Flow / Flow	Erosion
		Water level	Effluent quality
		Retention basins	Flow / Debit
Economic	Finances	Stimulation of the local economy	Water level
Social	Sociocultural	Value and land use	Retention basins
		Famous heritages	Stimulation of the local economy
		Religious monuments	Value and land use
		Middle traditions	Famous or known heritages
		Tourism and Leisure	Religious monuments
	Health	Health infrastructures	Middle traditions
		Diseases	Tourism and Leisure
	Security	Security level	Health infrastructures
	Human capital	Population and characteristics	Epidemics
		Employability level	Diseases
		Sectors of activity known to the project community	Accidents
		Housing	Occupational injuries
		Immigration	Security level
	Governance	Social responsibility	Population and characteristics
			Employability level
			Sectors of activity known to the project community
			Housing
			Immigration
			Social responsibility
			Conflicts of interest and management
			Ethics and corruption

Table 3. Summary of activities or mining operations in an OPM

Site preparation & Construction	**Operation & Maintenance**	**Closure & rehabilitation of the operated site**
Observation and mapping of the terrain	Drilling and blasting rock	Demolition of infrastructure
Exploration, sampling and sampling of geological and geotechnical data	Storing blasting products	Integrity of works (supervision and maintenance work)
Assessment of the potential for structural instability	Crushing and grinding	Environmental monitoring
Mineral resource estimate	Washing	Rehabilitation of the land
Completion of other related studies such as EIA with assessment of the cost of restoration	Sieve and particle size distribution if applicable	Monitoring the quality of the effluent
Clearing, stripping, weeding, cleaning	Collection	Monitoring the quality of groundwater
Drying and leveling	Transport of chemicals	General management of residues
Trench opening at the deposit	Concentration and processing of ore	Agronomic monitoring
Management of topsoil, till and waste rock	Evacuation of water and effluents from the open pit	
Drilling and blasting / felling of rock	Ore transport	
Disposal of water from the settling pond (if it existed)	Management and handling of ore in terminal phase	
Changes to watercourses and wetlands (if applicable)	Management of waste rock and tailings	
Construction of site roads and installation of surface lighting, including lighting	Surface water management	
Slope construction	Management of petroleum products	
Installation and construction of infrastructures	Fuel warehouse	
Pit design (geological, economic, financial and operational considerations)	Fire and management	
Excavation of the catch basin and settling basin	Slope failure	
Installation of on-site lighting	Spills of fuel or other spills	
Warehouse for blasting / slaughtering products	Site maintenance, repairs and installation of lighting	
Lighting of transport routes	Failure of the catch basin or settling basin	
Operations involving the use of mobile equipment	Environmental monitoring at predetermined intervals	

These initial categorization phases made it possible to obtain a readily, expanded and available spectrum of knowledge of dynamics resources, mining operations and VECs that will be used to design and develop the matrices.

2.4 Importance and Significance Calculation

Several matrices have been developed for different specific applications and among them, Leopold's matrix is the most general with a wider application. In this term, Josimovic, Petric, and Milijic (2014) show how the matrix draws a clear line and safeguards of evaluation synthesis from value judgments or policy makers to present a detailed assessment results. Initially, Leopold matrix is a semi-qualitative environmental impact assessment method pioneered in the last century by Leopold, Clarke, Hanshaw, and Balsley (1971). So, by facilitating the interactive participation of varied, hierarchical and antagonistic experts with stakeholder knowledge or opinions as valid input to research in an inexact research area, this matrix is an adequate tool according to Hai, Gobin, and Hens (2014). But, its most distinctive feature is his allowance to meta-analysis of issues to be investigated. This matrix provides a multi-criteria assessment of the possible impacts of an organization's activities in the project stage. Also, matrix tool like Leopold's can take into account both quantitative and qualitative data that correspond to the values found and this is the exact context of environmental studies.

The matrix is built by a detailed list of mining operations in the vertical axis and a system of selected factors in the horizontal axis. It is presented as a cross-functional table with different box where significant interaction is marked symbolically or by calculated values.

Under the quotation system indicated below in table 4, the magnitude and significance of each impact are respectively calculated. Then, some statement of activities and environmental factors are retained. According to logic matrices development, the importance of impacts (see Appendix A) and the qualitative analysis, the weighting is substantially similar. The weighting here varies from 1 to 10 both for the magnitude and significance of the impacts. Some values can go beyond 10 but, when this maximum is reached, it’s maintained at 10. It’s important to note that another purpose of this paper is to generate a matrix of OPM in operation.

Table 4. Determination of the significance value of an environmental impact

Weight (W)	**Magnitude (M) ou severity**	**W**	**Time (T)**	**W**	**Probability (P)**	**Corresponding weight**	**Significance**
1−3	Negligible	1	Punctual	1	Rare	**M+T+P = I** **NB**: if **I** > **10** then the weighting of **I** remains **10**	Negligible
4−6	Low	2	Medium	2	Likely		Low
7−8	Median	3	Long term	3	Effective		Medium
9−10	Strong or irreversible	4	Irreversible				Strong

3. Analysis of Results

The objective of this extensive work is to present an enhanced dynamic matrix system to facilitate a systemic evaluation of environmental impacts in any OPM. It also aims to observe the variability in the parameters related to the risks. These approaches reduce the following-up monitoring weaknesses and allow managers to assess the efficiency of mitigation measures. As this research aim is to minimize negative risks on OPMs sites, this research outcomes point out all the environmental factors sensitive to the variations over time of mining operations as well as the variability of the parameters themselves (from the project to the operating step).

3.1 Recapitulation of Potential Environmental Risks and Activities in OPM

The summary of mining activities or operations in OPM shows many fluctuations from one state to another. Table 3 lists the mining activities from the site preparation to the closure and rehabilitation of the mined ore site. But as it is shown in table 5, these activities vary once operations are executed. There are more than 4 activities in addition to those listed in an EIA. After preparation and construction, the operations, increase to thirteen activities once the mine is in operation. It should also be noted that the volume of an operation becomes larger after getting the permission notice. In the same way, there are fluctuations in environmental parameters from a mining project to a mine in operation. Table 2, shows some elements of the major groups of factors known as physical, biological and human, which can increase tenfold in several different sub-activities. Indeed, the predictions of risks may require reviews, additions, derivatives or duplications to follow closely.

Table 5. Fluctuations in the activities listed at the EIA elaboration and after the mine in operation

EIA matrix	**Matrix post EIA**
Slope construction	**No activities to mention**
Installation and construction of infrastructure	
Pit design (geological, economic, financial and operational considerations)	
Excavation of the catch basin and settling basin	
Installation of on-site lighting	
Warehouse for blasting / slaughtering products	
Lighting of transport routes	
Operations involving the use of mobile equipment	
Drilling and blasting rock	Drilling and blasting rock
Storing blasting products	Storing blasting products
Crushing and grinding	Loading, crushing and grinding
Washing	Excavation of fragmented blocks
Sieve and particle size distribution if applicable	Collection and loading of ore blocks in trucks by skips or shovels
Collection of ore	Ore transport before primary treatment
	Temporary storage of ore, where appropriate, according to form and areas
	Wash if necessary

	Temporary storage 2 of the ore if necessary according to the form and the area
	Grinding if necessary
	Sieve and particle size distribution if applicable
	Sorted ore pickup if required
Transport of chemicals	Chemical transport and unloading
Concentration and processing of ore	Concentration and processing of ore
	Storage of residues
Evacuation of water and effluents from the open pit	Evacuation of water and effluents from the open pit
Ore transport	Ore transport
Management and handling of ore in terminal phase	Handling of terminal ore for shipping or sale purposes
	Transport of domestic and mining waste
	Waste rock management
Management of waste rock and tailings	Management of tailings
Surface water management	Surface water management
	Maintenance of rolling stock
Management of petroleum products	Reception of petroleum products
Fuel warehouse	Fuel warehouse
Fire and management	Fire: Crisis situation
	Fire: Prevention and Emergency Plan
	Management in case of fire
Slope failure	Slope failure
Spills of fuel or other spills	Spills of fuel or other spills
	Temporary plant shutdowns for maintenance
Site maintenance, repairs and installation of lighting	Site maintenance, repairs and installation of lighting
Failure of the catch basin or settling basin	Failure of the catch basin or settling basin
Environmental monitoring at predetermined intervals	Environmental monitoring at predetermined intervals
Demolition of infrastructure	Demolition of infrastructure according to the restoration program selected
Integrity of works (supervision and maintenance works)	Integrity of works (supervision and maintenance works)
Environmental monitoring	Environmental monitoring
Rehabilitation of the land	Rehabilitation of the land according to the restoration program selected
Monitoring the quality of the effluent	Monitoring the quality of the effluent
Monitoring the quality of groundwater	Monitoring the quality of groundwater
General management of residues	General management of residues (domestic, mining, waste and other waste)
Agronomic monitoring	Agronomic monitoring

3.2 Qualitative and Quantitative Data from Matrix of Symbol Values or Numerical Matrix

This section summarizes the project phase and operation phase impacts of the physical, biological, and social-economic-cultural components in OPM. A quick summary of the data output shows that the data vary from a matrix at EIA stage to a post-EIA status not only because of the activity or the affected environmental factors level but also fluctuate quantitatively (numerical) and qualitatively (symbolic). These analyses assume that activities or environmental components could change speedily, promptly or briefly over time and between processes. Two types of dense matrices were developed: symbolic and numeric (see Appendix B and C). The symbolic matrix cannot be considered as the numerical matrix. Its data remain qualitative and the conclusions are approximate since the majority is retained. For its own part, the numerical matrix provides with much greater detail on the: 1) need to make environmental monitoring more dynamic and therefore interactive; 2) ecological significance of such effects; and 3) emphasis on environmental factors and the mining system. Such details on the basis of regular updates that come with the evolution of the environmental risks during the lifetime of the mine.

3.2.1 Qualitative Data Results from the Matrices with Symbol Values

Table 6. Qualitative data results on an open-pit mine (OPM) project

Impact typology	Positive *but* ***negligible***	***Minor*** positive	Positive ***average***	***Major*** positive	Negative *but* ***negligible***	***Minor*** negative	Negative ***average***	***Major*** negative
Synthesis	4	14	53	145	32	162	329	323

Table 7. Qualitative data results on post EIA of OPM

Impact typology	Positive *but* ***negligible***	***Minor*** positive	Positive ***average***	***Major*** positive	Negative *but* ***negligible***	***Minor*** negative	Negative ***average***
Synthesis	0	28	37	75	101	123	533

Table 6 and 7 present the synthesis values of the results from the numerical matrix, which clearly, demonstrates the negative environmental risk activity that mining represents even if there is a considerable rate of positive impacts.

In addition to this outcome from the qualitative data, it is interesting to point out, on the one hand, the impact of activities on each part of environment components and in the second hand, the incidence of all mining activities during the mines' life cycle.

3.2.2 Quantitative Data Results from the Numerical Matrices

In each impact cell of the numerical matrix, there are two numbers above and below the diagonal of each cell, respectively, indicating magnitude (from 1 to 10) and significance of the impact (from 1 to 10). Negative values do not always appear with the symbol (-) but the cell is always coloured whilst the positive cells are colourless. The calculation is simple and is limited to the sum of the values depending on the activities on the line of each factor of the affected environment.

Therefore, the magnitude weight of «construction of site roads and installation of surface lighting» impact on geomorphological resources equals: (-)7 [7 (+ 0) = (-)7]. The significance weight of «construction of site roads and installation of surface lighting» impact on geomorphological resources equals: (-)10 : [10 + 0 = (-)10]. It is the same rule about positive impacts. But they always appear in unstained cells and since they are positive symbol in front of their numbers is always the (+) even if the sign does not appear in front of the number.

3.2.3 Summary of Matrices Analysis

Here, the results report the general degree of impacts of the project phase on different parameters, which are already known in the scientific literature, but not in this kind of numerical and symbolic details, for a total of six assessment table matrices.

Table 8. Environmental mining assessment scores on the project phase and post EIA phase

Project phase	PHYSICAL				BIOLOGY			HUMAN	
	Geomorphological	**Soil**	**Air**	**Acoustic**	**Vegetal**	**Wildlife**	**Water**	**Economic**	**Social**
Magnitude -	85	229	354	248	235	639	592	107	414
Significance -	131	345	551	384	355	721	949	149	554
Magnitude +	10	30	9	7	39	88	58	130	872
Significance +	12	44	17	13	44	101	91	181	1177

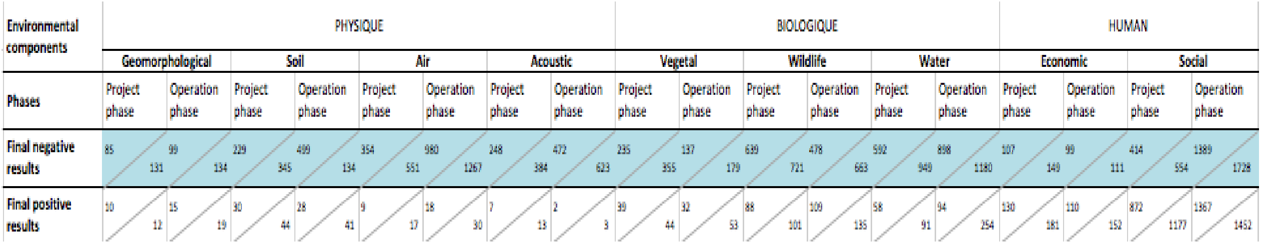
Post-EIA phase	PHYSICAL				BIOLOGY			HUMAN	
	Geomorphological	**Soil**	**Air**	**Acoustic**	**Vegetal**	**Wildlife**	**Water**	**Economic**	**Social**
Magnitude -	99	499	980	472	137	478	898	99	1389
Significance -	134	134	1267	623	179	663	1180	111	1728
Magnitude +	15	28	18	2	32	109	94	110	1367
Significance +	19	41	30	3	53	135	254	152	1452

<u>Legend</u>: ▨ Negatives values; ☐ Positives values

The table 8 lists two elements of the environmental factors negative scores for the project phase with the post-EIA phase in both magnitude and significance terms of general parameters.

3.2.4 Scores and Sensitivity Analysis: Project and Post-EIA phases

Figure 3 shows a picture of a table built in Microsoft excel to perform sensitivity analysis whose a clearer presentation is in Appendix D.



Environmental components	PHYSIQUE								BIOLOGIQUE						HUMAN			
	Geomorphological		Soil		Air		Acoustic		Vegetal		Wildlife		Water		Economic		Social	
Phases	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase
Final negative results	85 131	99 134	229 345	499 134	354 551	980 1267	248 384	472 623	235 355	137 179	639 721	478 663	592 949	898 1180	107 149	99 111	414 554	1389 1728
Final positive results	10 12	15 19	30 44	28 41	9 17	18 30	7 13	2 3	39 44	32 53	88 101	109 135	58 91	94 254	130 181	110 152	872 1177	1367 1452

Figure 3. Overview of the environmental components family score

Table 9. Summary of magnitude and significance of negative risks

	PHYSICAL		BIOLOGY		HUMAN	
	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase
Magnitude of negatives impacts score	-1388	-1578	-1466	-1513	-521	-1488
Significance of negatives impacts score	-1411	-2158	-2025	-2022	-703	-1839

The analysis of the numerical matrix at the post EIA stage highlights the high rate of negative risks on all physical, biological and human environmental factors. But, even in terms of physical and human factors, there is a growing difference between the magnitude and significance of risks, as from the project stage to the operational stage. However, the risks related to the biological factors from the beginning of the project to the operation phase maintain a regular, high rate but almost invariant as presented in the precedent table 9.

The figure 4 below describes how negative risks appear to be less important in EIA development but take on greater importance or are more affected once the mine is in operation. This vulnerable group of risky situations is a normal phenomenon that needs the attention of stakeholders, especially since this step is longer than the project phase.

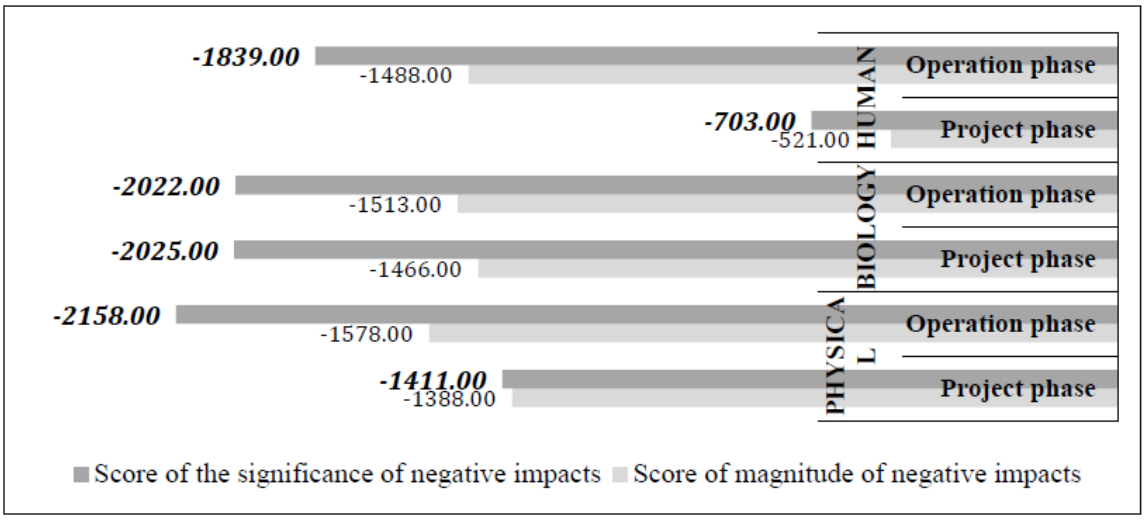


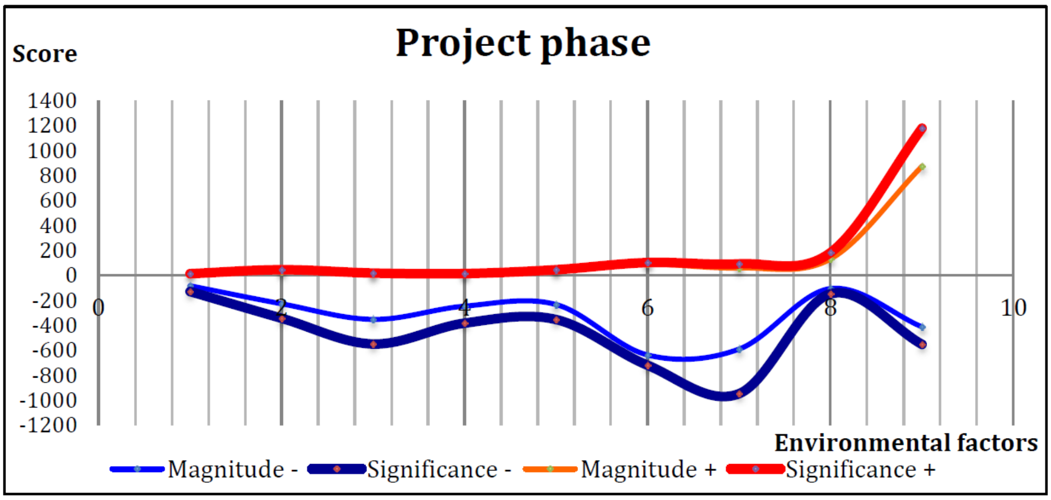
Figure 4. Plotted results of comparison importance level between negatives environmental risks

By observing the results, we notice that the negative risks, even if their weighting remains very high, the fact is that effect of the positive economic impacts is higher.

Table 10. Environmental factors parameters in order taken into account in the sensitivity analysis

1	2	3	4	5	6	7	8	9
PHYSICAL				BIOLOGY			HUMAN	
Geomorphological	Soil	Air	Acoustic	Vegetal	Wildlife	Water	Economic	Social

Geomorphological, soil, air, acoustic, vegetal, wildlife, water, economic and social parameters are considered in the sensitivity analyses in order to gain insight into the proposed hypothesis. In order to simplify the reading, these environmental factors are represented by numbers 1 through 9 in the order as shown in the table 10.



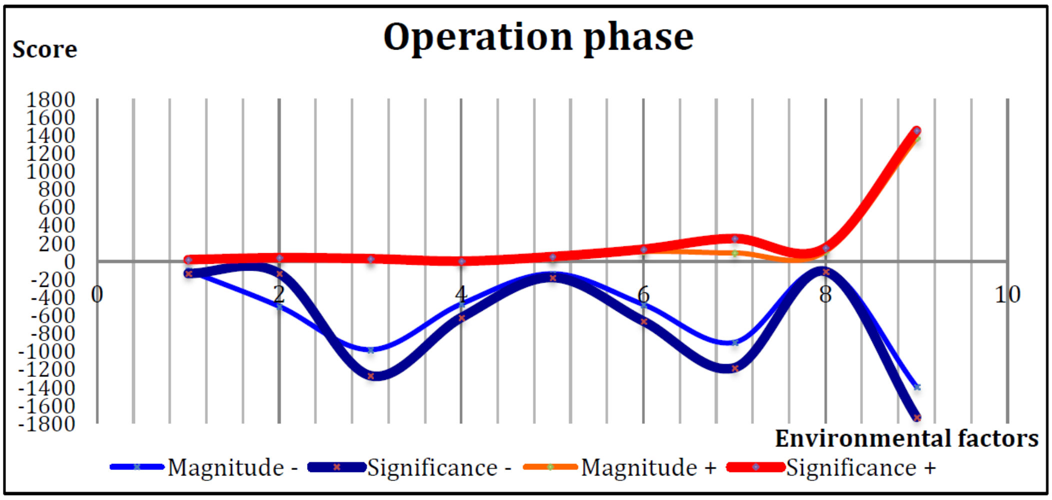


Figure 5. Sensitivity analysis: magnitude and significance risks evolution from project to operation phase depending on environmental factors

3.3 Disparities between the Level of Magnitude and Importance of Risks Observed

The results of these sensitivity analyses shown in figure 5 show a considerable disparity between the impacts weight on the VECs. These disparities between the level of magnitude and significance of environmental risks after summation of impact scores led to determine adverse or unavoidable impacts and the corresponding parameters to follow up. Indeed, by fluctuating over time, some variability parameters are highlighted and must be monitored. The figures also expose the magnitude and the significance of the negative risks especially, over time which joins the previous deductions. Soil, air, acoustic, wildlife, water and social are these factors subject to variations to follow closely.

Positive impacts do not need to be mentioned because they are not sources of harm to the ecosystem. But it remains necessary to emphasize that there are positive values because this investigation from the beginning takes into account the principles of wastewater management. A principle that any mine manager or other industrial infrastructure must have. However, the apparent invariability of factors 1, 5 and 8 (geomorphology, flora and the human) mean something else. They demonstrate their dependence on the other environmental factors.

4. Discussion

This paper brings round a new execution methodology mode of the assessment process to take appropriate mitigation measures for responsible environmental management in mining. The work proposes a technical approach with a major review process (of risks, VECs) useful for a better decision-making process for both academicians and practitioners. A necessity, since the alert is put forward by some authors like MacKinnon, Duinker, and Walker (2018) on the need to reconcile environmental management to a more adapted scientific methodology. Furthermore, to better ensure the EIA procedure to dynamic simulation technique, the research gives three specific contributions: 1) evolution, extent, significance, and magnitude of incurred risks; 2) the mitigation measures strategies by reading data horizontally or vertically; and 3) environmental mining management and dynamic monitoring options.

4.1 Evolution, Extent, Significance, and Magnitude Data

After collecting OPMs that met the criteria defined (exclusion and inclusion) a synthesis of the environmental parameters in different scientific languages has been made. This harmonization led to the reduction of repetitions, to a systemic summary of the considered factors in the mining industry and an appropriate outreach to all stakeholders. At the end of this first exercise, 58 environmental factors have been listed as shown in table 2 against 65 factors to the phase of mining operations. Subsequently, a summary of activities or operations is conducted for these mining activities in the state of exploration, project, construction, operation, and closure of the mine. 42 different activities are retained in the matrices of the operation phase compared to 50 in the project phase because that includes the exploratory and construction steps (see table 5). And the probabilities of negative or positive impacts spread across 2900 cells at the project phase (50 activities x 58 factors) and 2730 at the operational phase (42 activities x 65 factors). Then, the obtained impacts are individually (according to each activity) or sequentially, numerically, qualitatively and therefore globally also (due to aggravating factors). But, even if the negative risks are greater than the positive impacts, the 2900 and 2730 probabilities respectively do not make all impacts as shown sensitivity analyse (figure 5). Finally, the matrices highlight: 1) the potential environmental risks (from negligible to major); 2) the development or evolution of risks over time between the phases; 3) the interaction of risks with the other components of the system; 4) and their amplitude followed by their significance on all affected environmental factors.

4.2 Mitigation Measures Strategies: Horizontal and Vertical Data

The results show that the incidences of mining activities during the lifetime of the mine are multiple and have complex causes due to interactions between operations and environmental factors. In order to remove or reduce negative environmental impacts, mitigation measures are identified right from the project conception. There are two known types: suppression and reduction measures at the source. In general, the suppression measures correspond to the alternative of eliminating impacts at the source (Baard, 2014; Gouvernement du Québec, 2018). They require a revision of the initial project by reconsidering aspects of development and exploitation. This in order to eliminate the negative impacts on the natural environment or the species exposed. While if a negative impact cannot be removed, the reduction measures serve to limit the influence of the anticipated negative impacts. The reduction measures may apply from time to time from the design of the project to the construction, operation and maintenance phases too. In this work, due to the observed changes and fluctuations in the weight of the impacts, an optimal application of mitigation measures is essential before the project construction and during the operations. However, such a measure will depend on the temporal behaviour of the risks and the concerned environmental factors. An approach facilitated here by computing horizontally and vertically the impacts scores.

When the obtained data are combined vertically, the scoring show how dangerous is each activity on each VECs and the stakeholders can choose another way to make this operation if it remains essential. When it is horizontally, the manager is able to better measure the sensitivity of environmental factors over the lifetime of the mine. By taking the example of a physical factor on noise pollution, major negative impacts remain throughout the life of the mine and will make the environment unbearable if no mitigation or suppression is taken. Moreover, as the mine gets older, a concentration of negative risks is more observed. These are the aspects that should challenge the parties involved in readjusting the environmental management of mining to increase the frequency of environmental monitoring so as to closely monitor sensitive factors and subject to strong and dangerous fluctuations.

4.3 Environmental Mining Management and Dynamic Monitoring Options

Indeed, the elaborated matrices ensure a temporal risk representation, from the mining project to, the mine in operation. The ability to provide values close to the realities of the environment over time is a particularly important aspect that directs the players in the environmental management of mining towards the integration of dynamics. This approach can serve as a bridge to dynamic management and the use of a dynamic simulation (DSi) in environmental procedures as analysed by Lagnika et al. (2017) by creating dynamic matrices for an adaptive management. The generated risk sheet can also serve as a basic reference for managers and users of EIA projects for mining projects from now on and within the framework of the environmental management.

The variations observed between the two phases confirm the importance of being careful about environmental factors changes or transformations or behaviour over time. Also, when an environmental component experiences a series of negative impacts as undergo the security, noise pollution, water, effluent quality, flora, etc. evidence of a regular environmental monitoring program with a rigorous application is a visible recommendation to adopt.

5. Conclusion

Properly managing environmental risks is at the top priority of many actors in the mining sectors' agendas. However, the process of sorting measures to mitigate or prevent risks and the monitoring program are most of the time structured in theory but often unstructured during the production. This failure or irregularity was also reflected in this academic research literature performed in this study.

And, even if there are more than hundred or thousand EIA studies realized in the world in mining, there are also more than a hundred methodologies used for. Yet, the harmonization of proceedings seems to be a meaningful way to recommend. To improve the environmental performance of mines and the performance of operations, this work helps practitioners to invest themselves in an adaptive environmental assessment and management by creating models of monitoring matrices. The establishment of a matrix as a primary tool for access clearance the negative, positive or negligible environmental risks at the project (with EIA) and the operation (post-EIA) phases, required elements from several orders to reflect the reality of extractive industries. Therefore, by dynamic symbolic manipulations and numerical solving or inferences, this is a contribution to a useful production information system for OPMs in Canada like elsewhere in the world and allowed to make an in-depth prevention of impacts. These dynamic matrices should be required hereafter in the environmental monitoring program and integrated into the mining plan to improve mitigation measures over time. And, systemically by a reverse engineering, here is a way to obtain values reflecting approximately the reality of the: evolution, extent, significance, and magnitude incurred during the mining's lifecycle.

As MacKinnon (2017) maintain that the global environment assessment (EA) enterprise is to fulfil the purpose to contribute to a sustainable pattern of development by protecting VECs, the researchers and practitioners must adopt a more collaborative, participatory, and scientifically rigorous approach to conduct future EAs.

Acknowledgment

The Ecole de technologie supérieure (ETS) supported this work via the following programs: Experimental station of pilot processes in the environment (STEPPE-ÉTS) and research officers. We also thank all the reviewers for their constructive comments.

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Appendix A

Importance of the impact according to the value of the component as well as the intensity, extent and duration of the impact

Value of the environmental component	**Intensity of disturbance**	**Extent of impact**	**Duration of impact**	**Significance of impact**		
				Strong	Average	Low
Higher	Strong	Regional	Long	x		
			Average	x		
			Short	x		
		Topical	Long	x		
			Average	x		
			Short		x	
		Punctual	Long	x		
			Average		x	
			Short		x	
	Average	Regional	Long	x		
			Average	x		
			Short		x	
		Topical	Long	x		
			Average	x		
			Short		x	
		Punctual	Long		x	
			Average		x	
			Short			x
	Low	Regional	Long	x		
			Average		x	
			Short		x	
		Topical	Long		x	
			Average		x	
			Short			x
		Punctual	Long		x	
			Average			x
			Short			x
Medium	Strong	Regional	Long	x		
			Average	x		
			Short		x	
		Topical	Long	x		
			Average	x		
			Short		x	
		Punctual	Long		x	
			Average		x	
			Short			x
	Average	Regional	Long	x		
			Average	x		
			Short		x	

		Topical	Long	x		
			Average		x	
			Short			x
		Punctual	Long		x	
			Average			x
			Short			x
	Low	Regional	Long		x	
			Average		x	
			Short			x
		Topical	Long		x	
			Average			x
			Short			x
		Punctual	Long			x
			Average			x
			Short			x
Low	Strong	Regional	Long	x		
			Average		x	
			Short		x	
		Topical	Long		x	
			Average		x	
			Short			x
		Punctual	Long		x	
			Average			x
			Short			x
	Average	Regional	Long		x	
			Average		x	
			Short			x
		Topical	Long		x	
			Average			x
			Short			x
		Punctual	Long			x
			Average			x
			Short			x
	Low	Regional	Long		x	
			Average			x
			Short			x
		Topical	Long			x
			Average			x
			Short			x
		Punctual	Long			x
			Average			x
			Short			x

Appendix B. Symbolic matrix on Excel sheet

Table B1. Post-EIA step matrix

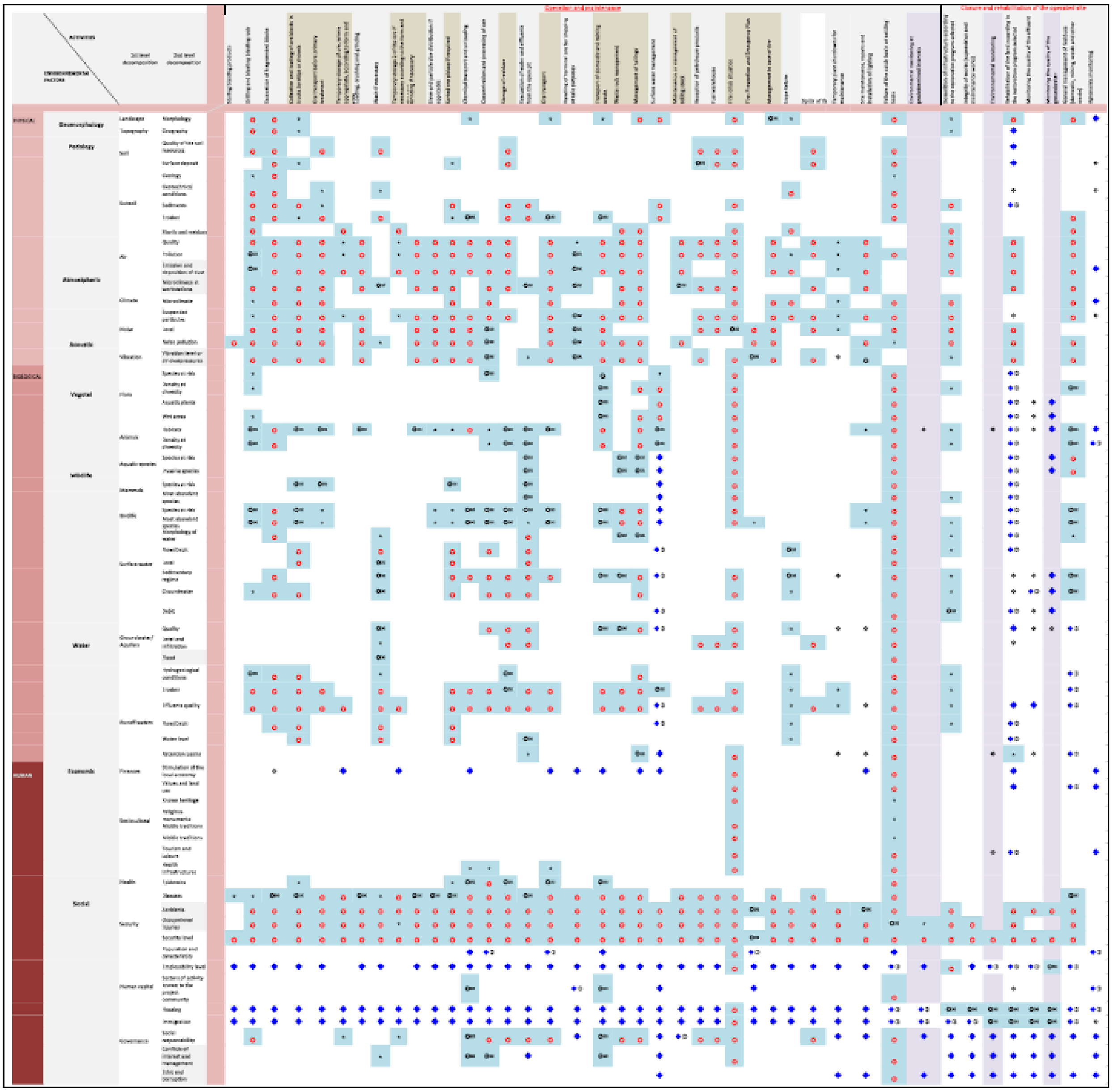
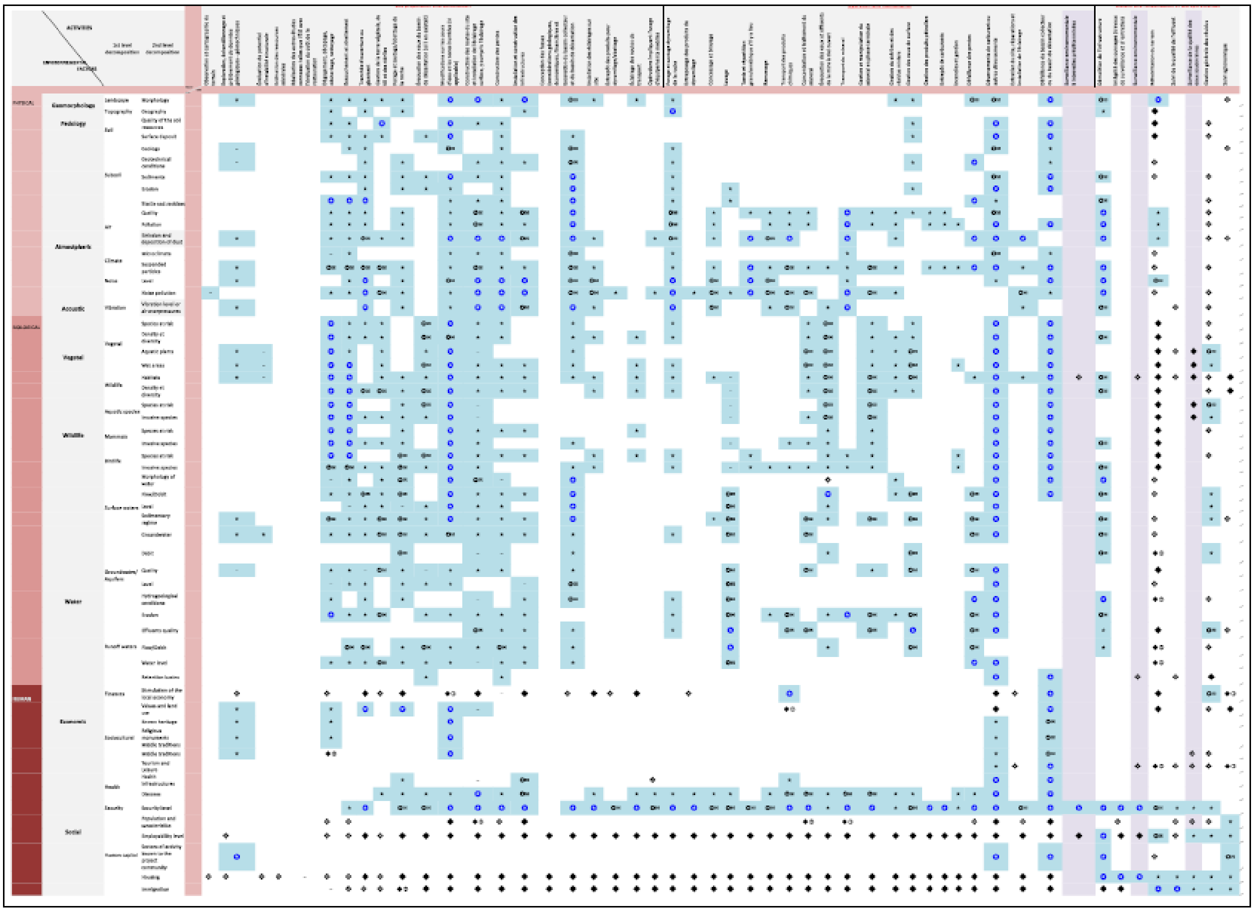


Table B2. EIA step



Appendix C

Numerical matrix on Excel sheet

Table C1. Post-EIA step

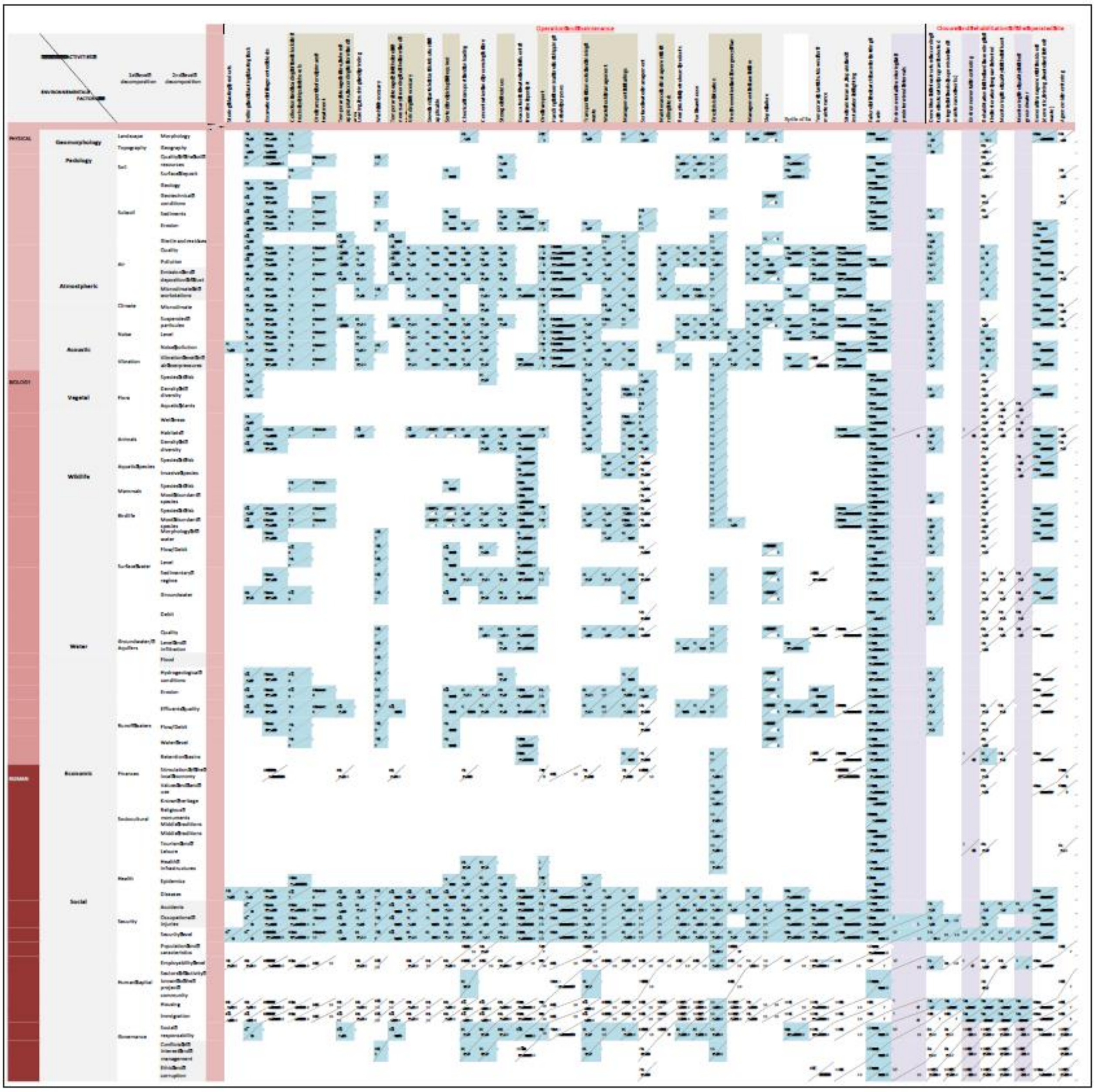
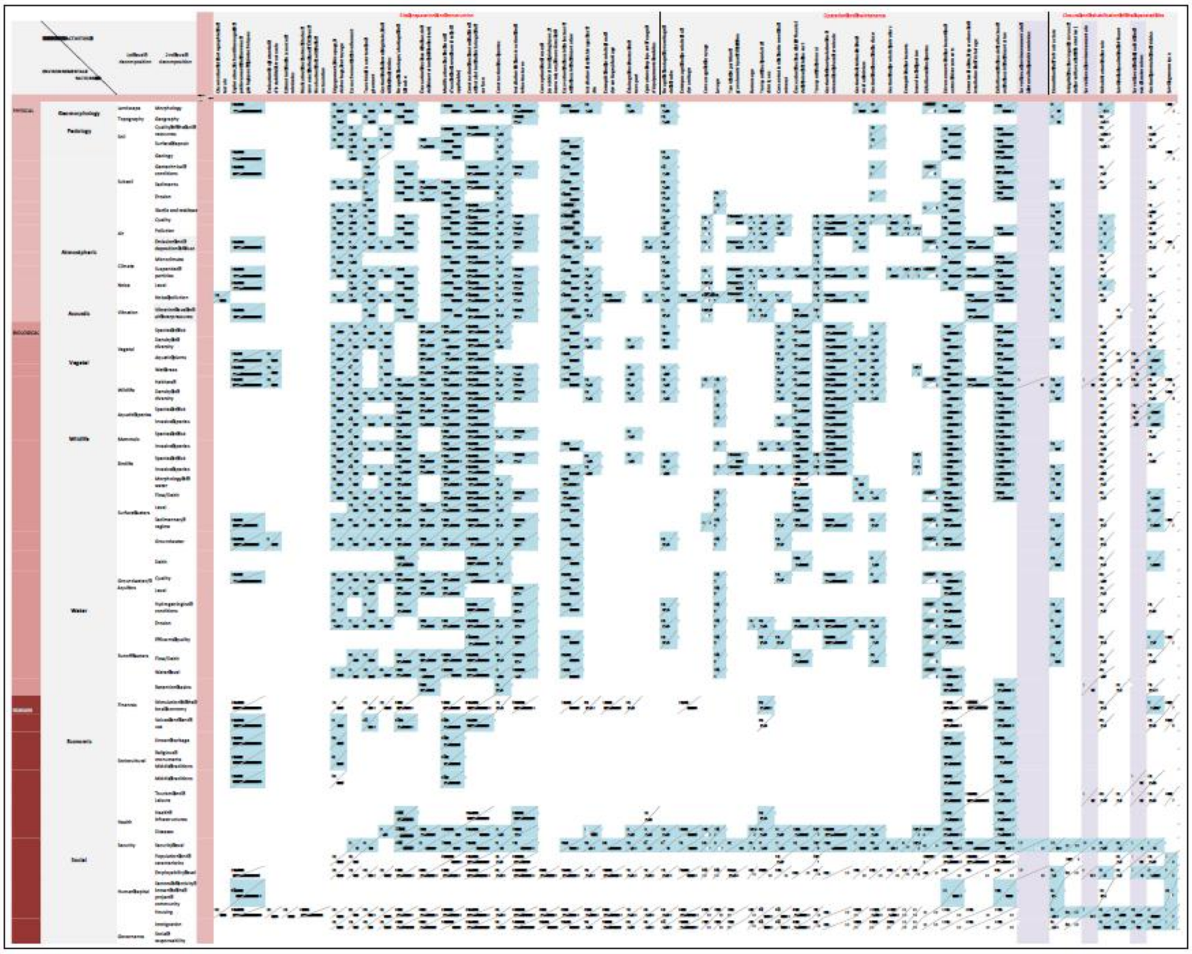


Table C2. EIA step



Appendix D

Overview of the environmental components family score

Environmental components	PHYSIQUE								BIOLOGIQUE						HUMAN			
	Geomorphological		Soil		Air		Acoustic		Vegetal		Wildlife		Water		Economic		Social	
Phases	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase	Project phase	Operation phase
Final negative results	85 131	99 134	229 345	499 134	354 551	980 1267	248 384	472 623	235 355	137 179	639 721	478 663	592 949	898 1180	107 149	99 111	414 554	1389 1728
Final positive results	10 12	15 19	30 44	28 41	9 17	18 30	7 13	2 3	39 44	32 53	88 101	109 135	58 91	94 254	130 181	110 152	872 1177	1367 1452

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