International Journal of Engineering, Sciences and Technologies
ISSN : 3079-2045
https://www.ij-est.org/

Volume 2, issue 2, https://doi.org/10.70961/RYQS2943

International Journal of Energy, Environment, and Economics

RISKS AND VULNERABILITIES ANALYSIS RELATED TO CLIMATE CHANGE FOR THE MALAGASY MINING SECTOR

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RESUME

Mining projects are subject to serious opposition from both local communities and environmental protection agencies, due to the potential devastation impacts associated with mining. At the end of a mine's life cycle, companies have an obligation to restore the vacant land. However, the mining sector is particularly vulnerable to the consequences of climate change, which can disrupt exploration and exploitation activities, or quite simply prevent the mobility of stakeholders, including staff. The mining sector therefore needs tools to enable it to integrate climate change into the design of structures and the planning of mining activities, hence the proposal for this study entitled the " risks and vulnerabilities analysis related to climate change for the malagasy mining sector ”. The main objective of this work is to identify the main elements of vulnerability to climate change in mining activities in Madagascar. To achieve this, two approaches were explored: the first approach consisted of the synthesis of information to highlight the environmental, socio-economic and institutional factors likely to characterize the state of sensitivity and resilience of mining activity in the face of variability and climate change. The second one focused on the processing of essential information for vulnerability, based on cross-referencing using statistical analysis techniques and the agile and adaptive project management method. The results of this analysis show that the main vulnerabilities of the mining sector in relation to climate change are at the level of site rehabilitation.

KEYWORDS

Project, ecology, evaluation, mitigation, adaptation, resilience, systemic.

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1. INTRODUCTION

In Madagascar, the mining sector is considered a real pillar of the country's development, with a view to fighting poverty. Indeed, mining generates significant economic benefits each year from a local, regional and national point of view. However, when we analyze its performance compared to other development sectors within the big island, and to other countries on the African continent, the Malagasy mining sector comes up against a lack of pragmatism in terms of rigorous economic footprints. Efforts still need to be made to make it more competitive.

From a global perspective, when we talk about sustainable development, the mining sector is generally at the center of discussions in terms of systemic risks and vulnerabilities [6], [36], namely, sensitivity on economic issues, sensitivity on social issues, and sensitivity on environmental issues [18].

When we talk about the environment, often in Madagascar, the mining sector is considered “devastating the ecology” throughout the exploitation phase, in other words, the mining sector is therefore dependent on climate change [36]. Thus, the measures are generally focused on the rehabilitation of mining sites and the social responsibility of the mining company carrying out a given mining project.

In relation to the aforementioned global principle, this study relates a point of view which is not yet sufficiently considered in the « big island »[1], even a rather reversed reasoning, this talks about climate change effects on mining sector [15], [31]. As hypothesis, we statue that: “the mining sector efficiency with regard to sustainable development are exposed to risks and vulnerabilities due to climate change”.

The reason why this hypothesis is put forward is, to consolidate the place in sustainable development in Madagascar, the mining sector must look for touches of innovation. In this context, it appears necessary to propose an axis of reasoning which proposes an improved basis for Malagasy mining project management, with the aim of aiming for better assured profitability based on better structured and more flexible support measures on the long term.

The expectations aim for better anticipation of projects with regard to climate change with a view to better adaptation and resilience face to climate change, note that all the actors and elements of sustainable development must be considered by the concept.

To carry out the analyses, this article first addresses a methodology for processing the risk and vulnerability analysis of the Malagasy mining sector in the face of climate change on the basis of documentation and literature reviews to highlight environmental factors. , socio-economic and institutional, likely to characterize the state of sensitivity and resilience of mining activity in the face of climate variability and change ; The second stage talks about risks and vulnerabilities treatments and tools implementation for Malagasy mining projects with regard to climate change, by using the crossing of technical statistical analysis tools with the agile and adaptative project management method.

At the end of the simulations, two results are expected. First, the proposal for the “canvas for managing the vulnerability of the project to climate change”. This framework leads to a model of climate change risk and vulnerability management tools applied to the malagasy mining project and sectors. These allow level of risks and vulnerabilities classification, and at

[1] Madagascar

the same time, reflections on appropriate mitigation supports according to each degree of priority.

In the case of this study, the simulation was focused on gold mining cases.

2. MATERIALS AND METHODS

2.1 – Processing methodology

2.1.1 – Objective and attempt

The objective of the study is to see how climate change affects a mining project, and how to challenge it [15], [31], [41], [43].

2.1.2 – Strategies and approaches

To do this, the study proposes the following approach:

- Consider a given mining project,
- Geographically locate the project,
- Heed climatic situations,
- Break down the project in relation to the different phases,
- Establish a climatic situations risk inventory,
- Establish climatic situations risk assessments,
- Establish climatic situations vulnerability assessments,
- Set performance criteria,
- Analyze cases: carry out simulations and comparisons of project performance,
    - Without climate change parameters,
    - With climate change parameters.

2.1.2 – Tools of achievements

To achieve this, the following tools must be used :

- Risk analysis standard, ARP [8], [21],
- Risk management standard : approach AS/NS ISO 31000 :2009[2] [29],
- Vulnerability analyzis standard [17], [28], [29], [32], [37],
- Computer and statistical tools,
- Agile and adaptative project management tools.

2.1.3–Treatment approach

The following steps are to be considered:

- Present a brief overview of the mining project, the Malagasy mining sector, concepts on climate change, as well as concepts on risks and vulnerabilities.
- Design the framework for mining projects vulnerabilities with regard to climate change treatments,
- Settle down treatments and calculation tables,
- Simulate treatments and calculation tables by considering ratical cases,
- Emphasize simulation and case studies results, and discuss about these results.

[2]Utilisé notamment en Australie et Nouvelle Zélande

2.2 –Mining project

2.2.1 – Overview about mining project

A mining project is a complex process, bringing together several actors and various risks. In this view of complexity, the health of each mining project entity taken individually affects the project as a whole, and the health of each project affects that of the mining sector as a whole. In terms of risks, considering profitability constraints, timing factor and prospecting quality can be fateful if adequate measures are not analyzed beforehand. Indeed, investment costs are made today while profits are made in the future, with consideration of systemic risk and surprise of mining project life cycle. Also, the mining project is sensitive to cases of major socio-political, geopolitical, economic, and currently climatic forces.

In order to choose suitable technical and economic approaches for a best investment decision making, it is more than necessary to collect data that will allow calculations, forecasts and risk analyses. This step requires not only the collection of a large amount of information, but also the consideration of various technical, socio-economic, demographic, geographical, spatial and temporal parameters.

2.2.2 – Mining project and sustainable development

To evaluate the analysis results of a mining project, three main point of view axes are mainly considered: economic and financial analysis, social analysis and environmental analysis. The notion of balance between these three poles satisfies the basis of sustainable development mainstay: three fundamental criteria are necessary, namely:

- Economic efficiency : it means ensuring a profitable project following a fair rent sharing rate between stakeholders, following sound and sustainable management. The objective is to develop a socio-political situation favorable to the realization of mining projects in “partnership” with Foreign Direct Investors (FDI), local economic actors and the driving forces behind the smooth running of the project.
- Social equity : it involves meeting basic human needs in housing, food, health and education, by reducing inequalities between individuals, while respecting their cultures.
- Environmental quality : it involves preserving natural resources in the long term, maintaining major ecological balances and limiting environmental impacts, in other words, project quality that does not harm man and environment.

2.2.3 – Phasing and management of mining project

A mining project can be broken down into five different main phases, namely:

- **the exploration and evaluation phase of the deposit**: This stage includes the regional exploration campaign(s), exploration of targets and an initial estimate of resources (« Maidenresources report » or « Technical report »)
- **the feasibility study and project design phase** : This stage includes the conceptual economic study (« Concept study» or « ScopingStudy » or « PreliminaryEconomicAssessment »), the prefeasibility study (“Prefeasability

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report”), the feasibility study (“Feasability report”), the detailed engineering of the project, and the arrangement of the financing required for production,
- **The mine development phase,**
- **The exploitation phase** and
- **The mine closure phase.**

Note: The exploration and evaluation phase are not carried out in this study.

2.3 – climate change overview

2.3.1 – Climate change phenomena

These are changes in the state of climate over time that can be identified (physically and statistically) over long periods of time, usually decades or more [4], [10].

These changes may be due to natural variability or by human activities[3] [13], [14], [21], [26].

Throughout the world, climate change is mainly manifested by [3], [5], [15], [38], [50], [55] :
- global warming accelerations,
- droughts proliferation of all over the world
- rise in sea level today exceeding the level of 4.4 mm per year,
- rainfall contrasts
- severe flooding,
- melting of polar ice
- extreme weather phenomena, such as frequent devastating cyclones or devastating hurricanes.

2.3.1 – Climate change impact and mitigation

Climate change affects all areas of activity [3], [9], [28], [33], among others, the mining sector. Nowadays, to face climate change, there are numerous studies and reflections [7], [24], [46], [48]. However, malagasy mining project related to climate change documents still rare.

2.4 – Risk and vulnerability assessment

Risk assessment and vulnerability assessment are two different concepts. However, their complementary use is important to establish a reliable risk management solution. On this path, the combined use of the two concepts has an important part.

2.4.1 – Risk assessment

The term “risk” measures the level of danger of a scourge likely to affect an entire process or project (or its components, or its stakeholders).

To establish an estimate of the level of risk (R), it is necessary to analyze the probability of occurrence of the risk (probability simply named (P)) and its serious consequences (incidence simply named (I)).

In this way this formula is used: $R=P*I$

[3] Groupe d’experts intergouvernemental sur l’évolution du climat [GIEC]

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In the case of study, the minimum incidence is assigned a score of 1, and the maximum incidence a score of 4.

To assess risks, the following procedures must be put in place, namely risk identification, risk analysis and assessment [8], [21].

2.4.2 – Vulnerability assessment

The term "vulnerability" [2], [3], [14], [16], [20] designates the capacity of the project (or its components, or its stakeholders) to manage risk. Vulnerability assessments not only help close process security gaps but also ensure standards compliance.

The level of vulnerability (V) is calculated by $V=Pv*Iv$, in which Pv is the probability of the vulnerability occurring and Iv is the impact of climate change on the project.

In the case study, the minimum vulnerability is assigned a score of 1, and the maximum vulnerability a score of 4.

2.4.4 – Vulnerability treatment, mitigations, adaptations

A vulnerability assessment may begin with a risk assessment, after which it is developed further to predict how well the project will be protected against potential risks.

Une évaluation de la vulnérabilité peut commencer par une évaluation des risques, après quoi elle est développée davantage pour prévoir dans quelle mesure le projet sera protégé contre les risques potentiels.

In this way, the following steps must be respected: identification of assets and risks, design of the basic structure, identification of vulnerabilities and vulnerability report, this allows reflection on mitigation measures [25], [27], [52], [53].

In the case of the proposed study, the analysis of the vulnerabilities of the mining project in the face of climate change, with a view to adaptations [40], [42], [48], [49], is particularly oriented towards production, deadline and quality of deliverables.

2.4.5 – Risk and vulnerability analysis support

When parameters are settled down, the following step is the process drawing up [17], [29], [32], [37]. The processing framework represented by figure n°1 presented in appendix 2. This framework helps in the analysis of a mining project by knowing the main phenomena of climate change, by inventorying the risks linked to these phenomena, and finally, by analyzing the vulnerability of mining projects according to the risks linked to these phenomena.

2.4.6 – Vulnerability level matrix

When parameters and supports have been established, the results are presented according to two cases: the vulnerability of the project before mitigation and the vulnerability of the project after mitigation.

To find the level of vulnerability after mitigation, the mitigation analysis focuses on the tenacity of the project against risks, the resilience of the project against risks, the responsiveness of the project against risks and the adaptation of the project against risks.

3. RESULTS

Volume 2, issue 2, https://doi.org/10.70961/RYQS2943 ISSN : 3079-2045

3.1 - The assessment framework for the Malagasy mining project vulnerability to climate change

Initially, the first result obtained concerns the pilot tool for the implementation of a matrix for analyzing the vulnerabilities of a mining project in the face of climate change. The framework, represented by Figure n°2 in Appendix 2, relates the different phases of the project to the risks arising from climate change. The operation consists of thinking about how the successful completion of a mining project would be vulnerable, and which components of the project elements would be most sensitive to climate change. Knowing these elements allows you to think in advance about the appropriate measures to take.

3.2 - The assessment framework operating matrix

3.2.1 – Basic settings

The basic elements are climate parameters, climate change, the effects and impact of climate change, the targets concerned, the key phenomena, the identification of risks and the effect of risks.

Taking the case of mine closure as an illustration of the use of the assessment framework operating matrix with above basic parameters, results are presented in the table n°1 in appendix 1.

The mechanism of correlations between these basic parameters is governed by the following logic: a given climatic parameter is exposed to a change. This change creates effects and impacts on a target element or on the phasing of the project (following a view focused on the elements of sustainable development). These effects and impacts are evidenced by key physical phenomena. These phenomena are sources of risks, and finally, these risks bring notable effects to the sound foundation of the project.

3.2.2 - Matrix of risks and vulnerabilities of a mining project in relation to climate change

The danger level of each risk is calculated according to its probability of occurrence and its level of incidence. Likewise, the level of vulnerability of the project, through its target element, is evaluated according to its probability of occurrence and its level of impact. Taking the case of mine closure as an illustration of the use of the matrix, the risk and vulnerability analysis matrix is given in table n°2 in appendix 1.

3.2.3 - Vulnerability Analysis Guidance Matrix

In the case of this study, the analysis of the vulnerabilities of the mining project in the face of climate change is particularly focused on production, deadlines and quality of deliverables. Taking as an illustration of the use of the matrix the case of the closure of the mine, the axes of analysis of risks and vulnerabilities are analyzed according to table n°3 in appendix 1. It should be noted that in this simulation, each axis (including production, deadline and quality of the project) is considered affected 100% by climate change.

3.2.4 - Vulnerability Level Matrix

To find the vulnerability level after mitigation, the mitigation analysis focuses on the tenacity of the project against risks, the resilience of the project against risks, the responsiveness of the project against risks and the adaptation of the project against related risks to climate change, according to mine closure stage, results are presented by the table n°4 in appendix1

3.3 - Summary of mining projects vulnerabilities to climate change simulations – target parameters: mining staff, the exploitation phase (production), the mine closure phase

To summarize the averages obtained for the three target parameters (mining staff, production, mine closure phase) through the risk and vulnerability simulation matrix, table n°5 representing the vulnerability of mining projects according to the targets “personnel, operating phase, closure phase” is created. This shows that the level of risks linked to the mining project considered is high in the closure phase, overall average of 54.63%, the production phase takes second place with an average of 45.97%.

In terms of vulnerability to risks caused by climate change, project execution staff are the most exposed, with an overall average of 68.75%. Unlike the level of risk, the vulnerability of the project with regard to the closure phase has no weight compared to the other two targets, overall average of 64.35%.

In terms of climate change risk mitigation capacity, the conditions staff and production exposure are more controllable than those relating to the closure of the mine. Indeed, the closure of the mine is directly related to the environment and the climate while mechanical and strategic means of intervention are possible for the staff and production exposure to climate change.

So, the aforementioned situation justifies once again the fact that the mining project is more vulnerable to climate change from the point of view of mine closure. In figures, the closure phase brings 18.31% of vulnerabilities compared to 9.54% for the operation phase (Production) and 9.03% for staff.

3.4 - Summary of mining projects vulnerabilities to climate change simulations – influences on productivity, time and quality

By distributing the risks and vulnerabilities of the project in the face of climate change, in relation to the constraints of productivity, deadlines and quality, the results are presented in table n°6 in appendix 1. This matrix shows that the level of risks imputed by climate change at the quality level is higher than at the productivity level and the deadline, this level is 50.21% compared to 45.06% for the other two constraints.

Regarding the vulnerability of the mining project to climate change, the constraint in terms of quality is also predominant: 36.85% compared to 32.35% and 31.15% for the constraints of deadlines and productivity.

For mitigation measures, quality constraint proves more difficult to control than the other two constraints. The correlation of the quality constraint with the environment (closely linked with the closure phase could be a cause)

Speaking of productivity, although this target is less risky than the others, the vulnerability of the mining project linked to the latter, due to climate change, is greater than 10%. It is therefore necessary to pay attention to this even at the project design level.

4. DISCUSSION

The carried out analyzes have demonstrated that climate change has direct effects on mining projects: in the case presented, these effects are human, economic, as well as environmental. The presentation of the results is here restricted to the mine closure phase because this phase is represented by the most condensed data among others (with the aim of representing the minimum possible data given the limit of the file to present in terms of time and spaces).

In terms of practical usefulness, this “inverted” analysis makes it possible to better manage the mining project with a view to optimization, knowing that it is demonstrated here that climate change can be costly to the mining project from several angles of view. The proposed tool is intended to be interactive and intuitive for any mining project, in all cases.

4.1 - Proposed model accuracy

For the parameter values reflecting the effects of climate change on the mining project, the standard deviations are presented in table n°7 in appendix1. The differences do not exceed 1% except for staff. The reliability of the model is reassuring.

4.2 - Proposed model Limit

Knowing that in the proposed model, simplifying hypotheses were considered, the simulation with larger numbers of cases and projects could refine this first version of the tool for simulating the effects and impacts of climate change on the mining project.

CONCLUSION

Mining investment is difficult to control, both depending on the political situation and technical constraints. In addition to the analysis of complexities, topics around climate change are current. If usually, the mining sector is known as a factor of climate change and environmental degradation, this study evokes the opposite phenomenon: mining projects find themselves facing the dangers linked to the risks brought by climate change.

In the carried out analyzes, the vulnerability of a mining project to climate change is oriented from a social, economic and environmental perspective. In detail, the targets are the the mining staff and related actors concerned, the operating phase and productivity, and finally the closure phase. In conclusion, the vulnerability of the mining project is higher during the mine closure phase than the other targets.

From another angle of view, climate change makes a mining project vulnerable in terms of productivity, compliance with deadlines and quality issues surrounding the project. Among these three points, the quality issue is the most sensitive.

Considering the scarcity of documents that reason from the same point of view like this, this study tries to show originality and an innovative approach in terms of design and management of mining projects in Madagascar, with a view to contributing to the sustainable development of the country, through the strengthening of the mining sector, in its role as a supposed pillar.

By pushing further, it is hoped that this work can serve as a tool and support for stakeholders in the sector for the establishment of more adapted, more robust and/or more resilient projects face to climate change, but also, projects able to take responsibility for managing climate change phenomena, knowing that a better understanding of the nature of climate risks and physical impacts, and the formulation of better plans to prepare for and adapt to these risks, can result not only more resilient mines, but also more flexible and secure local economies, as well as stable, prosperous and more responsible local communities.

AKNOWLEDGMENTS

This article is produced thanks to the consent of the scientific day commission of the Polytechnic High School of Antananarivo, under the aegis of the Malagasy State, the Ministry of Higher Education and Scientific Research and the University of Antananarivo, as well as the support of sponsors VITOGAZ, THERMOCOOL, SEBTP, the French Embassy, MIRE and TATIRANO.

To all, we send our deepest gratitude.

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APENDIX 1 : TABLE LIST

Table n°1: Basic parameters applied to the case of the mine closure phase.

CLimatic parameters	Climate change	Effects and impact of climate change	Target concerned	key phenomenon	Risk identification	Effect of risks
Temperature	Extremely high in summer	Heatwave, drought	MINE CLOSURE	**Overheating of the ground**	difficult revegetation	***Ineffective revegetation***
			MINE CLOSURE	**Overheating of the ground**	need more water than normal	***Ineffective revegetation***
			MINE CLOSURE	**Overheating of the ground**	need more water than normal	***Conflict with the local population***
			MINE CLOSURE	**Vulnerability of young plants**	young withered plants	***Failed revegetation***
			MINE CLOSURE	**Overheating of watering devices**	poor production capacity	***Ineffective revegetation***
	Extremely low in winter	Frost, humidity, fog	MINE CLOSURE	**Effect of frost on young plants**	young withered plants	***Ineffective revegetation***
			MINE CLOSURE			***No effect***
Sea level	Increase	strong agitation of the seas	MINE CLOSURE			***No effect***
		flooding of coastal areas	MINE CLOSURE			***No effect***
		frequency of devastating cyclones	MINE CLOSURE	**sinister**	disruption of operations	***poor performance***
		frequency of devastating cyclones	MINE CLOSURE	**Floods**	young dead plants	***Failed revegetation***
		frequency of devastating cyclones	MINE CLOSURE	**Floods**	erosion	***additional OPEX expenses***
		frequency of devastating cyclones	MINE CLOSURE	**Rockslides and landslides on site**	accidents	***disruption/stoppage of operations***
		frequency of devastating cyclones	MINE CLOSURE	**Rockslides and landslides on site**	financial risk	***additional OPEX expenses***
Precipitation	Increase	Heavy rain	MINE CLOSURE	**Floods**	damage to equipment	***disruption/stoppage of operations***
			MINE CLOSURE	**Floods**	young dead plants	***Failed revegetation***

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			MINE CLOSURE	**Rockslides and landslides on site**	accidents	***disruption/stoppage of operations***
			MINE CLOSURE	**Rockslides and landslides on site**	financial risk	***additional OPEX expenses***
Soil moisture	decrease	Dry and arid soil	MINE CLOSURE	**Overheating of the ground**	vulnerability of young plants	***poor performance***
			MINE CLOSURE	**soil too compact difficult to work**	vulnerability of young plants	***poor performance***
			MINE CLOSURE	**soil too compact difficult to work**	fertilizers and other additional products to use	***additional OPEX expenses***
			MINE CLOSURE	**waterproof floor**	vulnerability of young plants	***poor performance***
			MINE CLOSURE	**unfertile soil**	vulnerability of young plants	***poor performance***
Potential evapotranspiration	decrease	Heatwave, drought	MINE CLOSURE	**Overheating of the ground**	difficult revegetation	***Ineffective revegetation***
			MINE CLOSURE	**Overheating of the ground**	need more water than normal	***Ineffective revegetation***
			MINE CLOSURE	**Overheating of the ground**	need more water than normal	***Conflict with the local population***
			MINE CLOSURE	**Overheating of watering devices**	poor production capacity	***Ineffective revegetation***

Source : Author

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Table n°2 : Matrix of risks and vulnerabilities of a mining project in relation to climate change applied to mine closure

key phenomenon	Risk identification	Effect of risks	*Risk assessment : Probability*	*Risk assessment : Incidence*	*Risk assessment : Hazard level*	*Vulnerability assessment: Probability*	*Vulnerability assessment: Incidence*	*Mining project vulnerability level*
Overheating of the ground	difficult revegetation	***Ineffective revegetation***	4	4	**100%**	3	4	**75%**
Overheating of the ground	need more water than normal	***Ineffective revegetation***	4	4	**100%**	3	4	**75%**
Overheating of the ground	need more water than normal	***Conflict with the local population***	2	2	**25%**	2	4	**50%**
Vulnerability of young plants	young withered plants	***Failed revegetation***	3	3	**56%**	3	4	**75%**
Overheating of watering devices	poor production capacity	***Ineffective revegetation***	2	3	**38%**	3	4	**75%**
Effect of frost on young plants	young withered plants	***Ineffective revegetation***	3	4	**75%**	3	4	**75%**
sinister	disruption of operations	***poor performance***	2	4	**50%**	3	4	**75%**
Floods	young dead plants	***Failed revegetation***	4	3	**75%**	3	4	**75%**
Floods	erosion	***additional OPEX expenses***	3	4	**75%**	3	4	**75%**
Rockslides and landslides on site	accidents	***disruption/stoppage of operations***	2	3	**38%**	3	4	**75%**
Rockslides and landslides on site	financial risk	***additional OPEX expenses***	3	3	**56%**	3	4	**75%**
Floods	damage to equipment	***disruption/stoppage of operations***	3	3	**56%**	3	4	**75%**
Floods	young dead plants	***Failed revegetation***	3	3	**56%**	3	4	**75%**
Rockslides and landslides on site	accidents	***disruption/stoppage of operations***	3	3	**56%**	3	4	**75%**
Rockslides and landslides on site	financial risk	***additional OPEX expenses***	3	3	**56%**	3	4	**75%**
Overheating of the ground	vulnerability of young plants	***poor performance***	3	3	**56%**	3	4	**75%**

soil too compact difficult to work	vulnerability of young plants	***poor performance***	3	3	**56%**	3	4	**75%**
soil too compact difficult to work	fertilizers and other additional products to use	***additional OPEX expenses***	2	2	**25%**	2	4	**50%**
waterproof floor	vulnerability of young plants	***poor performance***	4	4	**100%**	3	4	**75%**
unfertile soil	vulnerability of young plants	***poor performance***	4	4	**100%**	3	4	**75%**
Overheating of the ground	difficult revegetation	***Ineffective revegetation***	2	2	**25%**	2	4	**50%**
Overheating of the ground	need more water than normal	***Ineffective revegetation***	3	3	**56%**	3	4	**75%**
Overheating of the ground	need more water than normal	***Conflict with the local population***	2	3	**38%**	3	4	**75%**
Overheating of watering devices	poor production capacity	***Ineffective revegetation***	3	4	**75%**	3	4	**75%**

Source: Author

Table n°3 : Vulnerability Analysis Guidance Matrix applied to mine closure

Overheating of the ground	***difficult revegetation***	***Ineffective revegetation***	***Production vulnerability***	***Timing vulnerability***	***Quality vulnerability***
Overheating of the ground	need more water than normal	Ineffective revegetation	3	3	3
Overheating of the ground	need more water than normal	Conflict with the local population	3	3	3
vulnerability of young plants	withered plants	Ineffective revegetation	3	3	3
Overheating of watering devices	poor production capacity	Ineffective revegetation	3	3	3
effect of frost on young plants	withered plants	Failed revegetation	3	3	3
sinister	disruption of operations	disruption/stoppage of operations	3	3	3
Floods	young dead plants	additional OPEX expenses	3	3	3
Floods	erosions	poor performance	3	3	3
Rockslides and landslides on site	accidents	poor performance	3	3	3
Rockslides and landslides on site	Financial risk	additional OPEX expenses	3	3	3
Floods	damage to equipment	poor performance	3	3	3
Floods	young dead plants	poor performance	3	3	3
Rockslides and landslides on site	accidents	Ineffective revegetation	3	3	3
Rockslides and landslides on site	Financial risk	Ineffective revegetation	3	3	3
Overheating of the ground	vulnerability of young plants	Conflict with the local population	3	3	3
sol trop compact difficile à travailler	vulnerability of young plants	Ineffective revegetation	3	3	3
soil too compact difficult to work	fertilizers and other additional products to use	Failed revegetation	3	3	3
Overheating of the ground	vulnerability of young plants	disruption/stoppage of operations	3	3	3
Overheating of the ground	vulnerability of young plants	additional OPEX expenses	3	3	3
Overheating of the ground	difficult revegetation	poor performance	3	3	3
Overheating of the ground	need more water than normal	poor performance	3	3	3
Overheating of the ground	need more water than normal	conflict with local population	3	3	3

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Overheating of watering devices	poor production capacity	Ineffective revegetation	3	3	3
Overheating of the ground	difficult revegetation	Ineffective revegetation	3	3	3

Source : Author

Table n°4 : mining project vulnerability level matrix face to climate change applied to mine closure

key phenomenon	Risk identification	Effect of risks	*Project vulnerability without risk mitigation*	*Mitigation related to project strength*	*Mitigation linked to project resilience*	*Mitigation related to project responsiveness*	*Mitigation linked to project adaptability*	*Total*
Overheating of the ground	difficult revegetation	***Ineffective revegetation***	2	2	2	2	50%	38%
Overheating of the ground	need more water than normal	***Ineffective revegetation***	2	2	2	2	50%	38%
Overheating of the ground	need more water than normal	***Conflict with the local population***	2	2	2	2	50%	6%
Vulnerability of young plants	young withered plants	***Failed revegetation***	2	2	2	2	50%	21%
Overheating of watering devices	poor production capacity	***Ineffective revegetation***	2	2	2	2	50%	14%
Effect of frost on young plants	young withered plants	***Ineffective revegetation***	2	2	2	2	50%	28%
sinister	disruption of operations	***poor performance***	2	2	2	2	50%	19%
Floods	young dead plants	***Failed revegetation***	2	2	2	2	50%	28%
Floods	erosion	***additional OPEX expenses***	2	2	2	3	56%	25%
Rockslides and landslides on site	accidents	***disruption/stoppage of operations***	2	2	2	3	56%	12%
Rockslides and landslides on site	financial risk	***additional OPEX expenses***	2	2	2	3	56%	18%
Floods	damage to equipment	***disruption/stoppage of operations***	2	2	2	2	50%	21%
Floods	young dead plants	***Failed revegetation***	2	2	2	2	50%	21%

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Rockslides and landslides on site	accidents	***disruption/stoppage of operations***	2	2	2	2	50%	21%
Rockslides and landslides on site	financial risk	***additional OPEX expenses***	2	2	2	2	50%	21%
Overheating of the ground	vulnerability of young plants	***poor performance***	2	2	2	2	50%	21%
soil too compact difficult to work	vulnerability of young plants	***poor performance***	2	2	2	3	56%	18%
soil too compact difficult to work	fertilizers and other additional products to use	***additional OPEX expenses***	2	2	2	2	50%	6%
waterproof floor	vulnerability of young plants	***poor performance***	2	2	2	2	50%	38%
unfertile soil	vulnerability of young plants	***poor performance***	2	2	2	2	50%	38%
Overheating of the ground	difficult revegetation	***Ineffective revegetation***	2	2	2	2	50%	6%
Overheating of the ground	need more water than normal	***Ineffective revegetation***	2	2	2	2	50%	21%
Overheating of the ground	need more water than normal	***Conflict with the local population***	2	2	2	2	50%	14%
Overheating of watering devices	poor production capacity	***Ineffective revegetation***	2	2	2	2	50%	28%

Source : Author

Table n°5 : Mining projects vulnerability of according to the targets "personnel, operating phase, closure phase"

Target concerned	*Risk report : danger level*	*Project vulnerability level*	Global Vulnerability level before mitigation	*Mitigation level*	Climate change effect level after mitigation
MINE PROJECT STAFF	42,03%	68,75%	28,89%	68,75%	9,03%
OPERATING PHASE	45,97%	66,39%	30,52%	68,75%	9,54%
MINE CLOSING PHASE	54,63%	64,35%	35,16%	47,92%	18,31%

Source : Author

Table n°7 : Mining projects vulnerability of according to the targets "productivity, timing and quality"

Target concerned	*Risk report : danger level*	*Project vulnerability level*	Global Vulnerability level before mitigation	*Mitigation level*	Climate change effect level after mitigation
PRODUCTIVITY	45,06%	64,99%	31,15%	65,07%	10,88%
TIMING	45,06%	68,25%	32,35%	68,07%	10,33%
QUALITY	50,21%	68,96%	36,85%	58,23%	15,39%

Source : Author

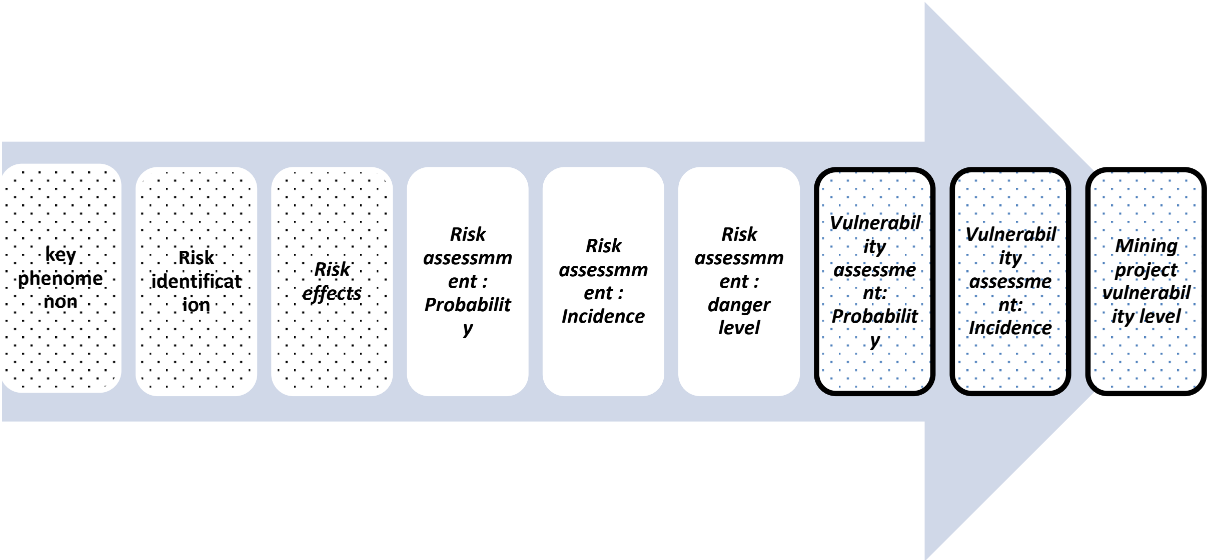
Table n°7 : Calculations standard deviations.

Target concerned	Climate change effect level after mitigation	Standard deviation
STAFF	9,03%	1,11%
OPERATING PHASE	9,54%	0,99%
MINE CLOSING PHASE	18,31%	0,20%
PRODUCTIVITY	10,88%	0,87%
TIMING	10,33%	0,16%
QUALITY	15,39%	0,87%

Source : Author

APPENDIX 2 : LIST OF FIGURES

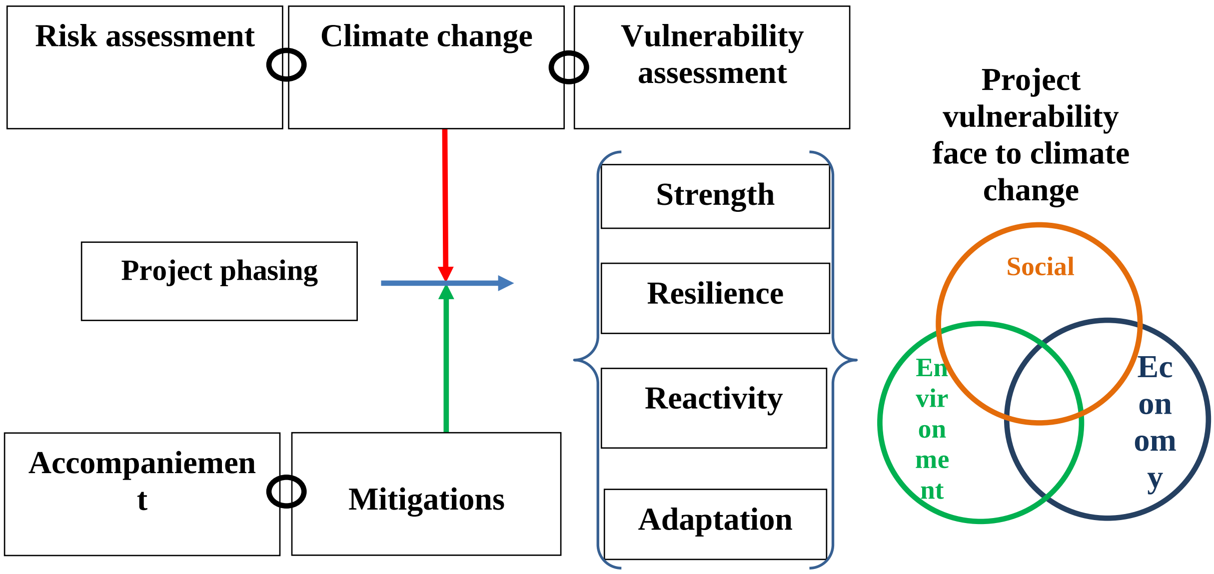
Figure n°1 : Mining project risk and vulnerability processing framework face to climate change



Source : Author

This figure represents the main process of dealing with climate change phenomena within the framework of a mining project.

Figure n°2 : The assessment framework for the Malagasy mining project vulnerability to climate change



Source : Author

This figure represents the systemic management of a mining project with regard to climate change phenomena:

- Upstream, knowledge of climate change phenomena, and thus, the level of risks and vulnerabilities of projects face of this,
- So, the preliminary measures (anticipations) to take so that the project is as resilient as possible