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Methodological proposal for the evaluation of strategic growth pathways for mining projects

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ABSTRACT

In 2022, Client Company (CC) independently conducted FEL1 studies for their Mining District Group 1 and Mining District Group 2, where various growth options were analyzed and the best alternatives for project sequencing were selected. In 2023, as part of the FEL-2A engineering study, CC needs to reevaluate its growth routes, but now in an integrated manner, considering the projects in both Mining District Groups together, to obtain a route that represents the best overall strategy for the Company, which does not necessarily correspond to the sum of the best local strategies.

The methodology proposed in this article for the evaluation of growth paths considers six fundamental stages. Stage 1 considers the update of the engineering of each field, passing the results through Tradeoff analysis of exploitation method and financial evaluations prior to the simulations. Stage 2 consists of preparing the necessary inputs for the operation of the SIMPLAN simulation tool, including the results of stage 1, plant process interaction criteria for each scenario, OpEx and CapEx scaling, among others.

With this, it is possible to perform the simulation model in SIMPLAN (stage 3), validating the results with the evaluations obtained in previous stages, and generating more than one thousand combinations of possible integrated production scenarios of the Mining District Groups. Then, in stage 4, the results are analyzed in PowerBi, generating a financial evaluation dashboard that is complemented with the non-financial evaluation of the routes; leading to stage 5, where each route is compared according to its Attractiveness vs Doability, which is how attractive it is from a financial point of view and how feasible it is from an environmental point of view, based on classifications of KPIs defined with the client. This analysis is complemented with the comparison of the simulated routes by means of a discounted NPV vs. CapEx graph, to discard scenarios that reduce the value of the integrated routes by adding mines to the analysis, ending with stage 6, in which the relevant recommendations are made for the client's growth routes.

1 INTRODUCTION

Project portfolio management requires making increasingly complex decisions based on multifactorial analysis, where sustainability aspects have taken a significant role (Dou et al., 2023), added to the aspects of economic return, production scale, useful life, process layouts, new technologies, and access to financing, among others (Smith, 2011). These analyses involve different areas and specialties, which promote and generate multiple production scenarios that differ, mainly, by changes in their boundary conditions, evaluation criteria, economics, and risks, with a strong component in their impacts on the environment, and therefore the possibility of obtaining and/or maintaining the license to operate.

The mining plans of each asset need to be done and updated under robust guidelines to reduce the risk associated to decision making under unrealistic objectives and strategies, incorporating learned lessons of previous performances (King, 2011). Thus, having a variety of robustly evaluated assets in a project portfolio takes importance, needing the development of multiple production scenarios considering the risks associated with internal and external factors, based on the probability of accomplishing the objective of each asset in a determined time and under certain assumptions, creating new production strategies as needed (Vann et al., 2012).

For this, a methodology is proposed for the evaluation of strategic growth pathways for mining projects, which increases the capability to identify, integrate and evaluate the various development alternatives that a mining company can follow, incorporating mineralogical, operational, financial, and non-financial variables, such as sustainability, environmental impact, and social impact. All based on reliable long term mining plans of their mining assets.

2 CHALLENGES ASSOCIATED TO THE PLANNING PROCESS

Planning is the engineering discipline in charge of defining the best strategy for the consumption of mineral resources, answering the questions "What?", "How?" and "When?" that define the exploitation of a mining asset, fulfilling the interests of the different stakeholders of the company. These questions are answered by having a strategy that allows maintaining the value of the business sustained over time, with enough flexibility in the short term to face risks associated with a changing market, without losing sight of the strategy.

Planning for district mining assets has the added complexity of having multiple mines that may share resources and processes throughout their useful life. This defines boundary conditions for planning on the basis that the optimum production of a mining asset will not necessarily be the optimum required for the business, from a district point of view and, therefore, from a strategy point of view. This presents a challenge for the management and planning of a portfolio of mining projects.

This challenge requires the ability to perform a multifactor analysis of scenarios with robust inputs that represent the reality of brownfield assets, and engineering of an adequate level for greenfield projects.

Simulation tools are required to support the planning process, considering the boundary conditions and selection criteria, which will guide decision making in the face of a large number of feasible scenarios. In the context of this study, the simulation tools used are characterized by the ability to reschedule plans based on changes to capacities of different components in the value chain of the mining operation, and the interaction of multiple mining assets with the aforementioned components, generating valorized mining plans.

This study focuses on a methodology for the management of multiple mining assets that share plant processes, considering the requirements to have reliable long term production plans and a multifactorial evaluation of productive scenarios. The scenarios are evaluated on a simulation software capable of the aforementioned analysis, focusing on the ability to reschedule plans based on different scenario constraints; including statistical distributions and evaluating sensibility scenarios are opportunities of the deterministic model that is being used, which doesn´t require considerable working hours to perform.

The mining plans used for the analysis were previously generated by the planning team following the guidelines discussed next.

The OpEx and CapEx estimations were made based on the client's guidelines, scaling them based on their fixed and variable components.

Resulting scenarios are compared based on their financial and non-financial rankings; the first one considers KPIs of economic value over time while the latter considers social and environmental impacts of the operation. Recommendations are selected based on discarding comparatively worse scenarios by these rankings (Attractiveness vs Doability) and added value of considering certain number of projects (by using an NPV vs CapEx graph).

3 PROPOSED METHODOLOGY

A strategic growth path analysis is a qualitative and quantitative analysis of multiple production scenarios of the company's mining assets, whose objective is to define the best strategy for the client's business, considering, among other parameters: operational continuity; economic return; financial results in accordance with the company´s objectives; non-financial criteria; environmental permits; risk and opportunity scenarios; enabling projects; activation or deactivation of assets; timing of asset development; investment schedule.

The step-by-step methodology proposed is presented in Figure 1, which considers the use of scenario simulation tools for an efficient and effective analysis of each alternative.

3.1 Project engineering

3.1.1 Integral Mining Business Planning System (IMBPS)

An Integral Mining Business Planning System (IMBPS) covers the entire value chain associated with the production and sale of minerals, incorporating both external and internal factors in decision making. For this, the different actors of the mining business must be included to generate mine-plant-port plans. These plans require base information representative of the reality of the company, so that there is a sufficient level of support to ensure proper decision making and increase the likelihood of meeting the goals proposed to the Stakeholders.

3.1.2 IMBPS Axes

The IMBPS conducts a sweep through seven axes, which are interrelated to each other. The axes correspond to the base characteristics on which the planning process is grounded, so that the planned is aligned with the operational, aiming to meet corporate goals based on a strategy permeabilized at different organizational levels, ensuring a mining business with low economic risk and sustainable value over time.

The "Robust" axis requires special attention, since it defines the base information on which we work, ensuring that the KPIs of each area involved in the planning process comply with quality standards (QA/QC), being reliable and representative of reality.

This base information is composed of standards, procedures, sufficiency evaluations and information validation, providing representativeness to the operation. With the information we expect to make robust models that add value to the data, which must be analyzed as accurately as possible. This is to perform all the studies and calculation methods, concluding with an efficient design recommendation, composed of established and tested parameters, relevant to any process. After the entire process, we proceed to use this design basis as a planning tool, through management

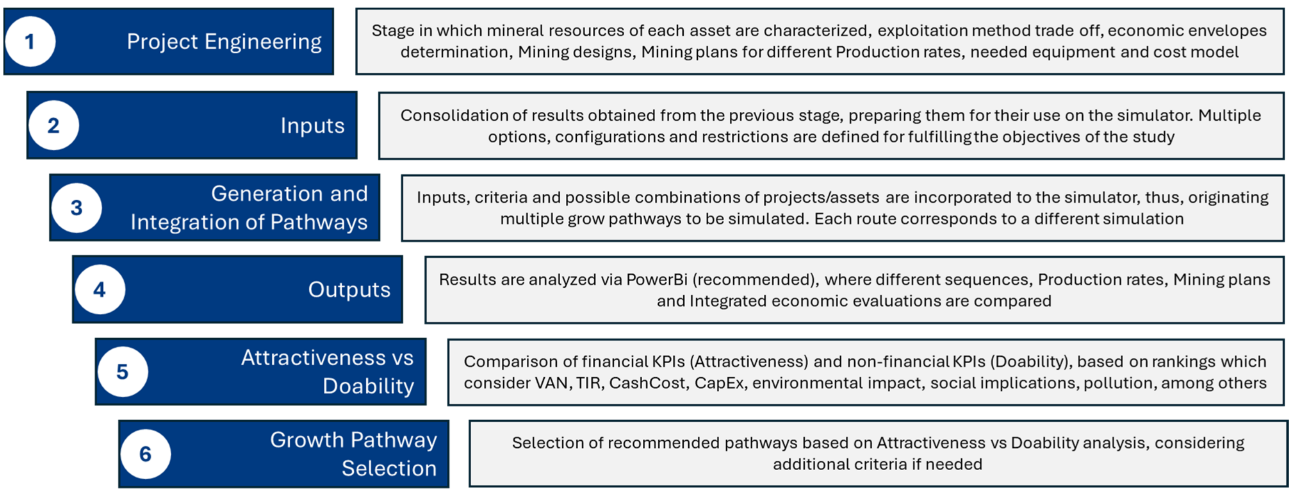

Figure 1 Growth pathway evaluation steps.

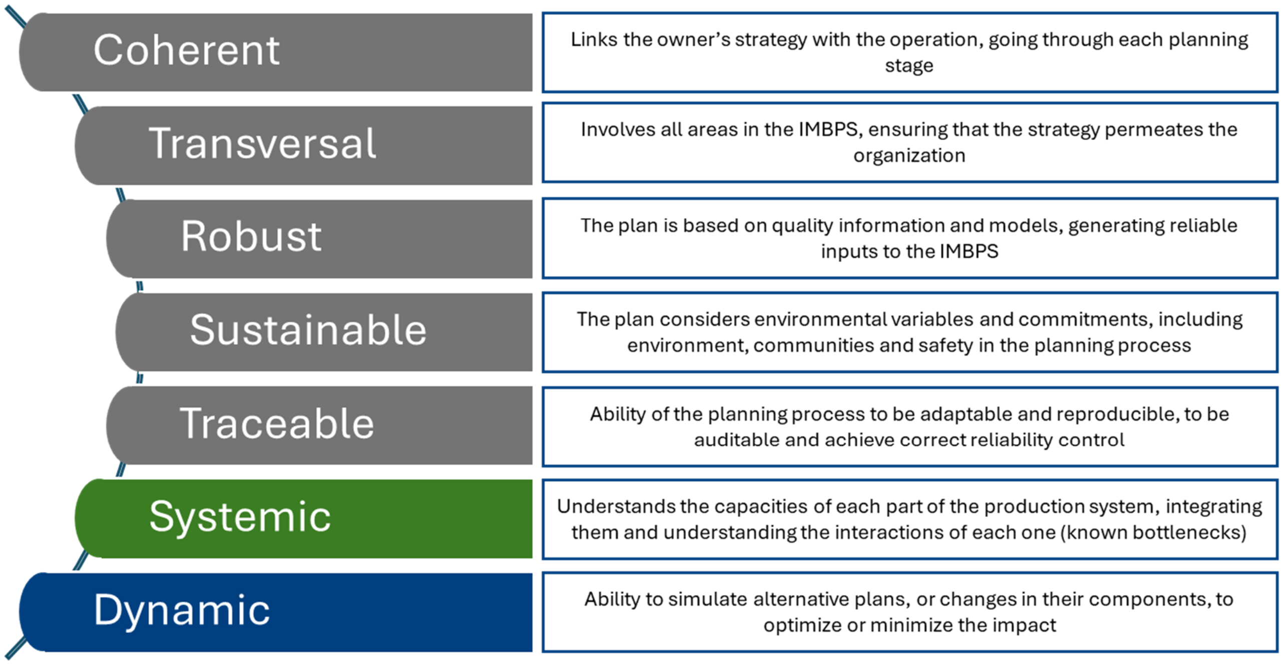

Figure 2 Planning axes.

and QA/QC controls, ensuring continuity and operational excellence. In addition, it allows the models to receive feedback at any time during their execution. These procedures are shown in

areas that integrate the value chain of the mining business.

By having reliable bases in terms of quality and quantity of information, it is possible to generate inputs and information deliveries that comply with the same guidelines and that together build and deliver robust inputs to consolidate the Planning System.

The planning bases take on special importance when adding flexibility to the plans generated. The knowledge of the KPIs that govern the different operations of the company's portfolio of mining projects is decisive when defining whether a planning process is systemic, offering the ability to achieve slack before unforeseen events in the operation, and strengthening risk analysis by focusing efforts on the 80-20 that afflicts each mining asset.

A systemic/dynamic planning system provides the necessary basis for an adequate management and planning of a portfolio of mining projects, defining a strategy aligned with the interests of the different stakeholders that also has adequate tactics for its implementation in the short and

Figure 3, located in a pyramid that sequentially contains the mentioned stages, according to the order of their realization and obtaining. Being the basis of all the information coming from the

medium term, considering flexibility in the face of risk scenarios of importance to the company. **The mining plans and production scenarios resulting from such a planning system are ideal for the development of a robust growth path analysis**.

3.2 Simulation tools

This study uses Simplan, software developed by Redco, capable of effectively integrating the constituent variables of a plan, considering the capacity restrictions corresponding to each link in the value chain of the mining plan, **rescheduling the plans** if the capacities/restrictions defined for a given scenario restrict or give slack to the input plan. The results obtained from the simulator range from the movement plan to the financial evaluation for a long-term study. The software works based on a plan detailed by transactions, which depends on the time granularity requested by the scope of the model. The methodology considers the integration of the simulations with PowerBi, which offers the opportunity to quickly analyze the multiple generated scenarios in a visual manner.

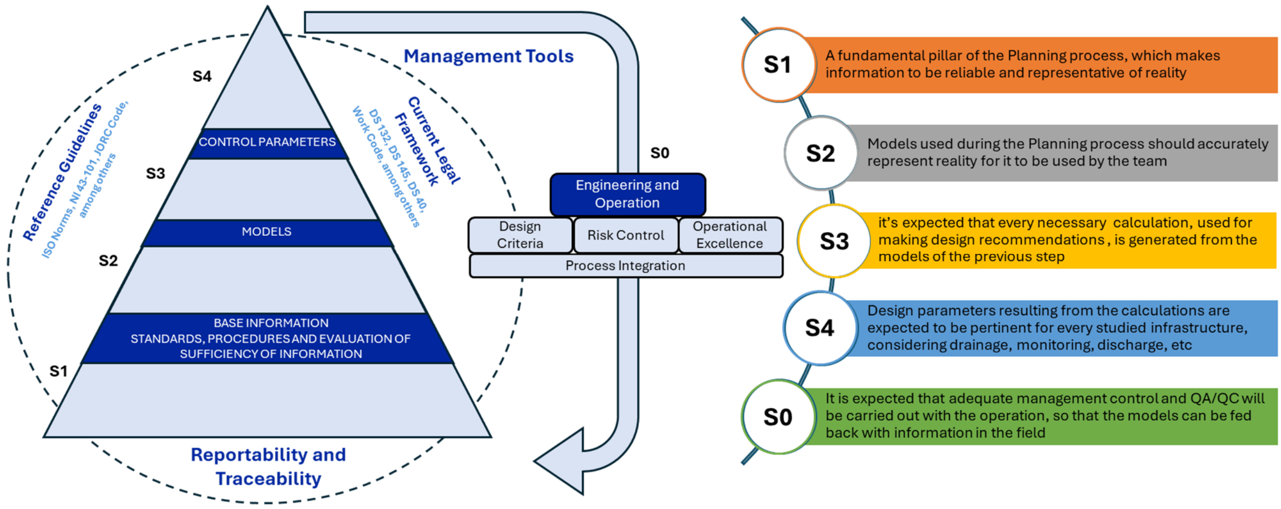

Figure 3 Planning Bases Stages.

This study generates different plans based on the base input plans. The route/pathway definition criteria will be discussed on the following sections.

The Mine-Plant-Port analysis performed in this study is deterministic, with the opportunity to generate a stochastic analysis of plan reliability, value at risk, bottlenecks, and parameter variability. Monte Carlo simulations are used for this regard, focusing on capacities, financial inputs and variables included in the input plan, such as Cu grade and solubility.

Any tool that lets the team to take multiple mining plans, set their mining start year and reschedule tonnage based on the interaction of capacities in the value chain could be used on this analysis.

3.3 Scenario Comparison

3.3.1 Financial Ranking

For the preparation of the financial ranking of the growth paths, a weighting of the ranking for NPV, IRR, CapEx Intensity and Cashcost is used. The definition of each item is presented below:

-NPV: Present value of cash flows discounted at the determined discount rate.

-IRR: Return offered by the investment, calculated from the NPV. The higher the IRR, the more attractive the investment option.

-CapEx intensity: Indicates the proportion of investment required to obtain an amount of product or concentrate. In this case it is calculated by the ratio between the total discounted CapEx and the total production of the pathway.

-Cashcost: Like the previous indicator, this parameter is calculated by the ratio between the total OpEx and the total production of the route. It is associated with how much it costs to generate one ton of concentrate.

The criteria used is presented below, where a ranking is defined given the minimum and maximum of each indicator obtained for the different routes, assigning a score from 1 to 6, depending on the location of the route within this ranking. The higher the score, the better the route. The scores assigned for each item in each route are weighted, in a next step, by the factors in Table 3, to generate the financial ranking for each route.

This ranking is sensitive to minima and maxima very distant from the average of each KPI, especially when there are mines with marginal value contribution, therefore, these routes are not considered in the definition of these limits and are classified with a score of 1 or 6 as appropriate, so that each pathway can be compared in detail. Obtaining the “Attractiveness” value of each scenario.

Table 1 Scoring criteria for financial ranking NPV and IRR

Criteria	Score
MIN+5*Range<Item Value≤MIN+6*Range	6
MIN+4*Range<Item Value≤MIN+5*Range	5
MIN+3*Range<Item Value≤MIN+4*Range	4
MIN+2*Range<Item Value≤MIN+3*Range	3
MIN+1*Range<Item Value≤MIN+2*Range	2
MIN≤Item Value≤MIN+1*Range	1

Table 2 Scoring criteria for financial ranking CashCost and CapEx Intensity

Criteria	Score
MIN+5*Range<Item Value≤MIN+6*Range	1
MIN+4*Range<Item Value≤MIN+5*Range	2
MIN+3*Range<Item Value≤MIN+4*Range	3
MIN+2*Range<Item Value≤MIN+3*Range	4
MIN+1*Range<Item Value≤MIN+2*Range	5
MIN≤Item Value≤MIN+1*Range	6

Table 3 Weighting of financial ranking items

Parameter	Weight
NPV	25%
IRR	25%
CapEx Intensity	30%
Cashcost	20%

3.3.2 Non-Financial Ranking

The non-financial ranking was made based on the qualitative and quantitative analysis from the previous study conducted by the Client, in which the following was considered:

-**Physical Aspects:** Such us space used by vital infrastructure, surface water effects, impacts to air quality and impact to natural resources.

-**Social Aspects:** Such as nuisance factors, impact on cultural heritage, impact on tourism, potential traffic disruption and proximity to populated areas.

-**Sustainability Aspects**: Such as emissions of equivalent CO2, electricity usage and water usage.

The criteria for the Physical and Social aspects are defined by the Client, while the Sustainability aspects are calculated during the engineering stage.

Quantitative aspects are ranked and scored using the same methodology used for the financial ranking, while the qualitative aspects get directly scored based on expert criteria. The resultant score for the Physical, Social and Sustainability aspects are then weighted by a 33% factor, obtaining the “Doability” value for each scenario.

3.3.3 Attractiveness vs Doability Analysis

Once the Financial Ranking and the Non-Financial Ranking have been calculated, the Attractiveness vs Doability graph is obtained. This is constructed by plotting on the X axis the score obtained from the Non-Financial Ranking, while the Y axis is constructed using the score obtained from the Financial Ranking. In this way, four quadrants are defined:

-Quadrant 1: Corresponds to routes with Attractiveness and Doability greater than three, i.e., they are considered attractive from the point of view of both the mining business and the environment.

-Quadrant 2: Routes whose Attractiveness is greater than three and Doability is less than 3, in this quadrant are the economically attractive options, but not so attractive from the environmental point of view.

-Quadrant 3: Corresponds to routes that are not attractive from any of the points of view.

-Quadrant 4: These are the routes that are attractive from an environmental point of view, but not as attractive from an economic perspective.

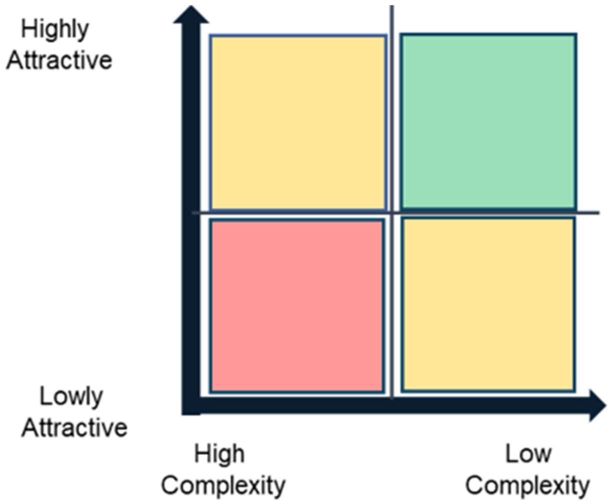

Figure 4 Attractiveness vs Doability.

3.3.4 VAN v/s CapEx Comparison

A VAN v/s CapEx graph is used to evaluate the increase or decrease of value to a growth pathway due to including more mining assets to the analysis, the base case, defined by Greenfield 1, is represented by the light blue point in the dispersion graph; each dot defines a new scenario. This is helpful for having visual understanding of the obtained results, observing tendencies and marginal differences with ease.

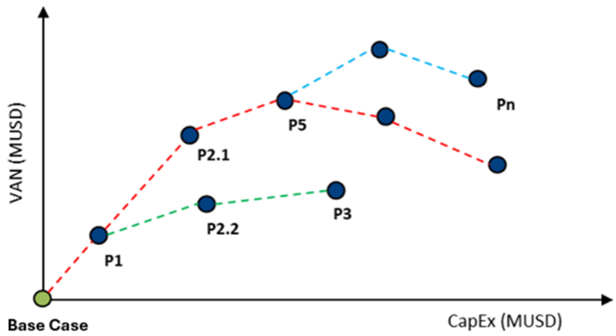

Figure 5 VAN v/s CapEx comparison.

This comparison is complemented with the capability to use production plans, financial results, and investment chronograms to guide decision making, and thus, choosing the scenarios that fulfil the Client's strategy more effectively.

4 CASE STUDY

The Client Company (CC) is a mining company currently operating in the north of Chile. The CC currently counts with a wide variety of mining assets divided in District Groups, named District Group 1 and District Group 2. The mining assets that are part of this study have an engineering level of FEL-2A, requiring a multifactorial analysis to determine the best operating strategy.

The District Group 1 consists of two Districts, District A and B, which consist of one brownfield mine and three greenfield mines; requiring a scenario analysis to determine the best production strategy, between having a district concentrator plant for each district, or a centralized concentrator plant for both districts (Figure 6), each scenario with its own capacity constraints for a shared port, denominated as Port 1.

District A is composed of the Brownfield 1 and Greenfield 1 mines, Brownfield 1 is a currently operating Open Pit mine that is planned to continue its operation by transitioning to a Sublevel Caving mine by the year 2050. After this transition, the concentrate production of the district will be reduced from 8.1 Mt/y to 3.5 Mt/y, which offers the opportunity to complement the operation with other mines by sharing preexistent infrastructure.

District B, on the other hand, consists of two greenfield projects that are meant to offer operational continuity to the District Group 1. Both mines mean concentrate production during their regimen operation is planned to be around 4.4 Mt/y. The scheduled start of mining is defined by the pathways generated by the simulations.

The simulated scenarios consist of two production strategies, Strategy A consists of having two district concentrators that feed the same port, while Strategy B consists of having a shared centralized concentrator. Their capacities, and the port's capacity, are defined by the needs of the generated pathways.

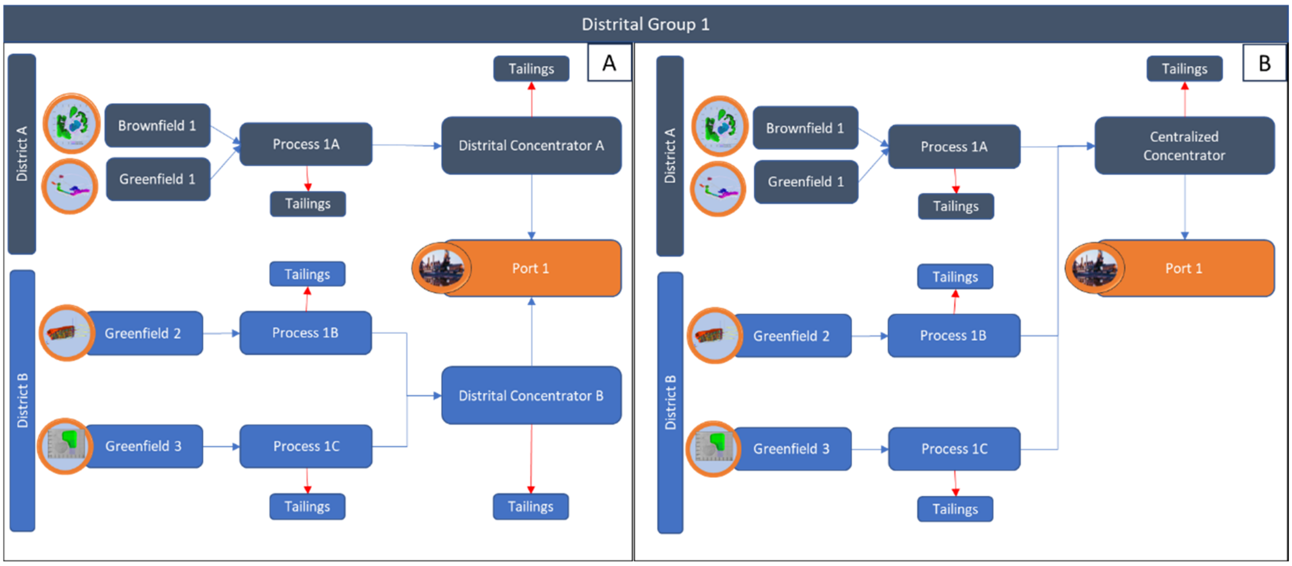

Figure 6 District Group 1 Layouts, A) District Concentrator; B) Centralized Concentrator.

The District Group 2 consists of one district, denominated as District C, which consists of two greenfield mines with a concentrator plant for each one (Figure 7). Due to the distance between the mines, there is no production strategy that considers a centralized concentrator plant. The Greenfield 4 mine is an Open Pit mine with a mean of 8.9 Mt/y of concentrate production during its regimen. On the other hand, the Greenfield 5 mine is a Block Caving mine with a mean of 7 Mt/y of concentrate production over its regimen. Greenfield 4 is considered to be scheduled at the first period of the pathways, before Greenfield 5 due to its better financial KPIs and not sharing infrastructure with the current brownfield project of District A. The start of the operation of Greenfield 5 and the capacities of the plants, and port, are a result of the pathway analysis.

For this, a study of Strategic Growth Pathways Analysis was conducted, which considered the following constraints:

- Use of simulation software and PowerBi for data analysis.
- Financial considerations that prolong the useful life of each District over time.
- Non-Financial considerations defined by environmental sustainability constraints.
- FEL 2A engineering level mining plans previously generated by our team.
- Process capacities defined by the Client.

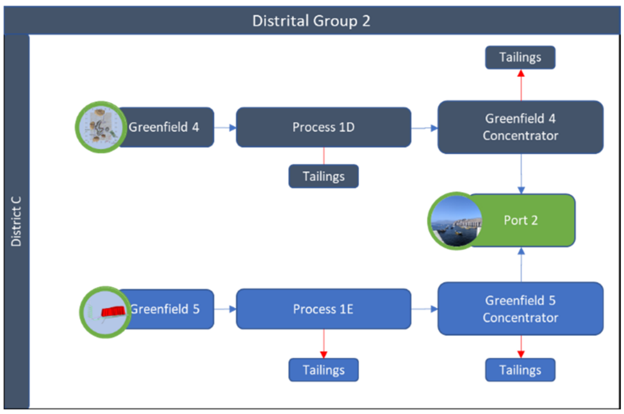

Figure 7 District Group 2 Layout.

4.1 Generation and integration of growth pathways

The different layouts were simulated considering the initial condition of Brownfield 1 starting its operation during the year 2029 for the District Group 1, meanwhile, the District Group 2 starts with the operation of Greenfield 4 during the year 2036, before Greenfield 5 due to their economic KPIs.

The other mining assets are included in the different growth pathways by considering production continuity scenarios, shared infrastructure, and a capacity for Port 1 of 9 Mt or 16 Mt of feed, depending on the simulated scenario.

5 STUDY RESULTS

The Mining plans used for this study were previously created by our team during the project. These plans are based on a first approach of the Client to an IMBPS, which is considered as sufficient for conducting the next steps of the proposed methodology.

A total of 1094 different scenarios were generated based on the plans and the Client's guidelines and constraints, the Attractiveness vs Doability graph shows them ranked as explained. Since most of the scenarios are similar in their non-financial KPIs, due considering similar infrastructure, effects over the environment and nearby communities, and emissions; the Doability axis is zoomed in for the comparison.

By the other hand, from the VAN v/s CapEx graph can immediately be observed that considering up to four assets in the growth pathways add value to the business, following the Client's strategy.

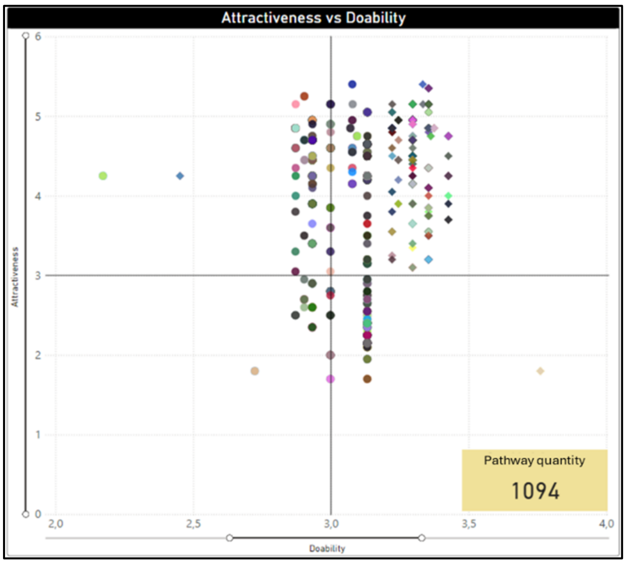

Figure 8 Attractiveness v/s Doability, results.

For the selection of recommended growth pathways, the following criteria was used:

1) Only pathways that belong to the first quadrant of the Attractiveness v/s Doability graph pass through the filter.
2) Any pathways that do not add value in VAN v/s CapEx from a previous number of mineral assets considered is filtered.
3) Strong criteria based on the strategy and risks analysis of the Client makes the final cut to determine which pathways are more valid to be recommended.

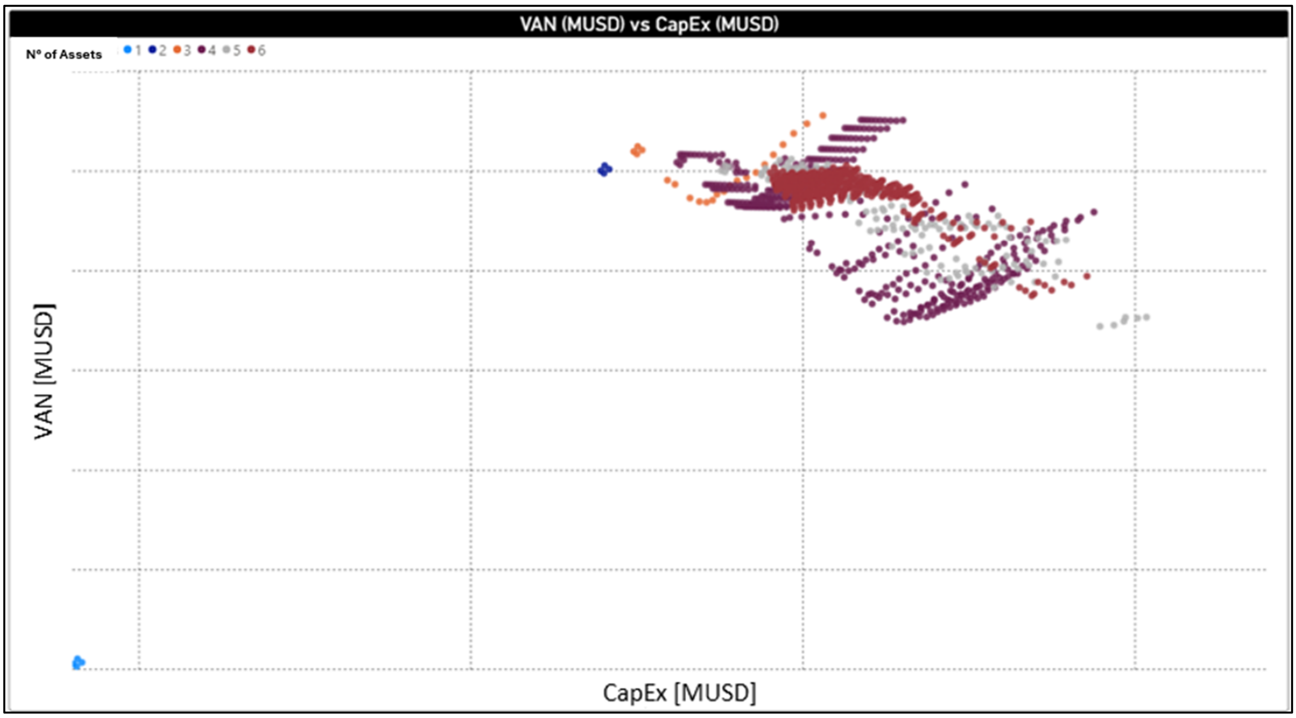

Figure 9 VAN v/s CapEx, results.

With this, five pathways are recommended for the Client to decide their course of action onwards. Each pathway is shown in the following graphs.

Figure 10 Attractiveness v/s Doability, final.

Finally, the recommendation as the most suitable pathway is pathway 2, which consists of a special case of pathway 1, considering a flexibility scenario that adds an additional greenfield project for growth strategic planning instances, increasing value at low risk at this engineering level.

6 OPPORTUNITIES

The presented methodology involves the analysis of deterministic scenarios, which can be complemented from this point onwards with

stochastic analysis via simulation software. This can be used to evaluate the impact of risk scenarios, opportunities, and market variations, among others, creating the necessary data for more consistent planning processes over time.

7 CONCLUSIONS

The strategic growth pathways analysis is an overly complex study that needs to be able to manage a varied range of variables, from items that are part of the planning process itself to items that are inherently tied to the business that is being performed.

The methodology presented on this paper could effectively manage the mining assets of the Client, considering their strategy, goals, risk evaluations, project portfolio, among other factors. Starting from having a consistent Mining Business Planning System, which is expected to reach the state of IMBPS in the midterm.

Plausible mining plans, complemented by a methodology that uses simulation tools and data analysis software proved to be the changing point to manage such a wide variety of scenarios that were in the hands of the Client.

From a total of 1094 scenarios. Five were recommended for future analysis, effectively guiding the decision-making process of managing the mining assets of this study. The next step is to increase the engineering stage of the assets the client ins more interested in and

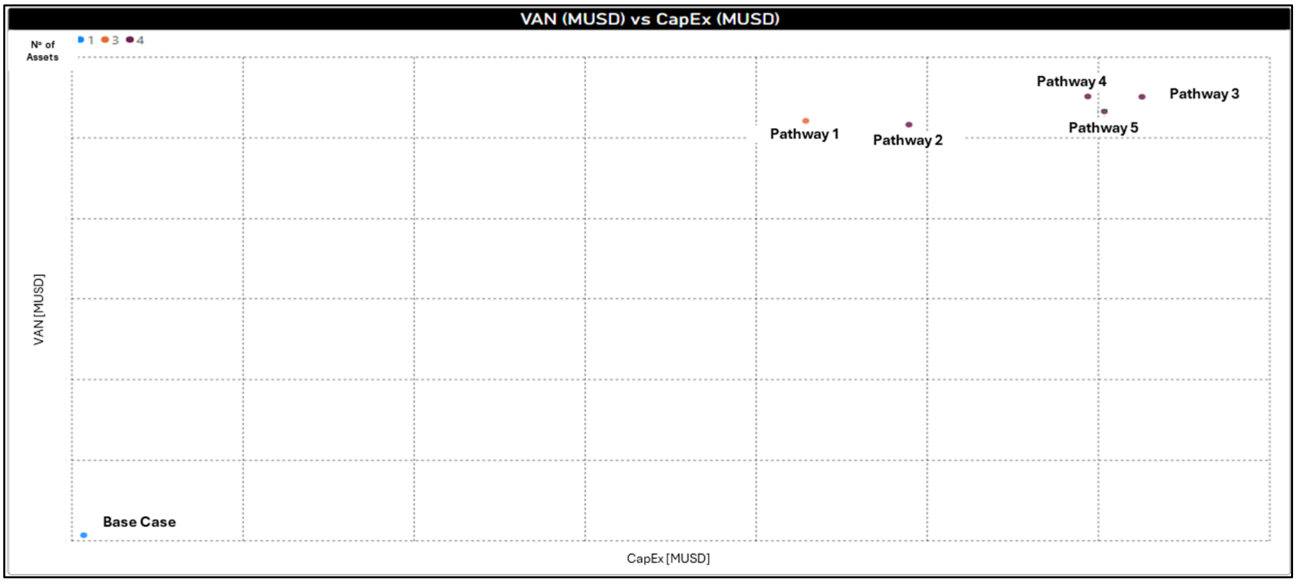

Figure 11 Attractiveness v/s Doability, final.

use stochastic simulations for risks analysis and reliability calculations. Task that can be done by updating the current deterministic model.

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