SUSTAINABILITY IN MINING, METALLURGICAL, CIVIL & REFRACTORIES INDUSTRY: DECISION MAKING MODELS FOR RECYCLING OF WASTES, CARBON DIOXIDE MITIGATING & CIRCULAR ECONOMY STRATEGIES

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ABSTRACT

The application of the concept of sustainability, through the implementation of actions and ESG (Environment, Social & Governance) policies, seeks in an inseparable way to achieve environmental improvements in the conduct of business. The mining, metallurgy, civil construction, and refractory materials production sectors have synergistic conditions for the solution and valorization of their waste generated during the life cycle of their products. The use of systematized tools for decision-making aimed at implementing technological recycling processes in order to guarantee the circularity of the product life and the essential reduction of consume rate of non-renewable resources. In this work, the Decision-Making Model for Recycling of Mining, Metallurgical and Materials Wastes (DM^2-4RM^{3}W) is presented to mitigate environmental impacts through the development of new products with properties capable of mitigating the impacts of CO_2 generation, landfill and mining wastes disposal based on technological development of waste-based products.

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1- INTRODUCTION

Sustainability is a very important concept, with roots from the “the Brundtland Report” and 92 Rio United Nations Conference on Environment and Development, where the “sustainable development” started to spread worldwide. [1]. As firstly defined in the Brundtland Report from UN (United Nations): “… *meets the needs of present without compromising the ability of future generations to meet their own needs*”, this definition could be expressed by a pictogram with 3 pillars, as shown at figure 1.

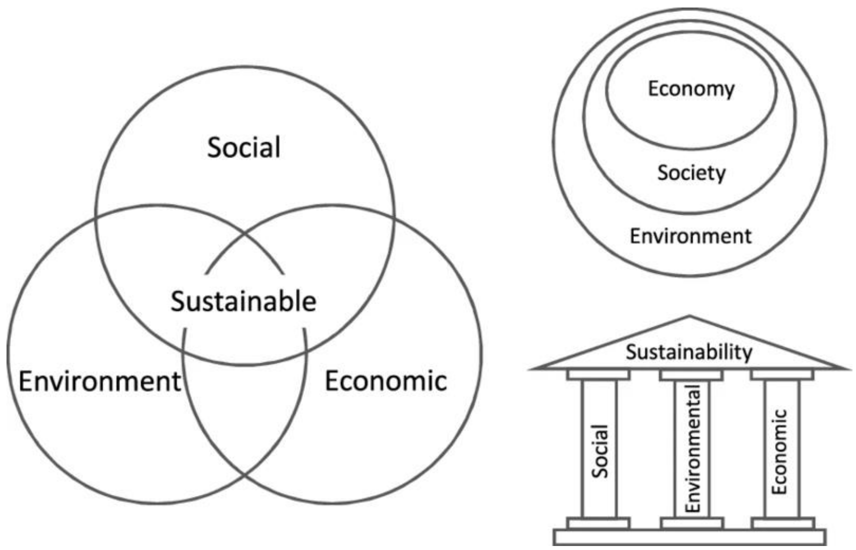

Figure 1 – The 3 pillars of sustainability [2].

The achievement of sustainability is not an easy task due the complexity of actions, however, the balance and integration of pillars are very important to adjust on the “trade-off” between of different dimension of sustainability. Table 1 shows the main aspects of an ESG program [3].

Table 1 – Main aspects of three dimensions of an ESG policy.

(E) Environment	(S) Social	(G) Governance
Non-renewable sources of raw materials	Poverty reduction	HSE&R (Health, Safety, Environment & Risks) standards polices and management
Wastes treatment: Reduce, Recycle & Reuse / Circular economy	Community relations	Compliance & Corporate responsibility
Loss of biodiversity	Social actions	Strategic & Innovation investment in the future
Effluents & pollutants treatments: solid, liquid and gases	Diversity & Human Resources	Anti-corruption actions
Consumption reduction (water, resources, energy, etc.)	Ethics, equity & inclusion (DE&I)	Transparency, Trustful & Timing of action
renewable energy: sources and uses	Human rights	Control & accountability
Carbon footprint: CO_2 generation, mitigation & CCS technologies	Well-being of employees, neighbourhoods, and stakeholders	Internal & public communication

2 - ENVIRONMENTAL IMPACTS OF MINING, STEELMAKING, REFRACTORY INDUSTRY AND CIVIL CONSTRUCTION

Mining, steelmaking, refractory industry, and civil construction are very bonded by the intensive use of materials, energy, natural resources and consequent CO_2 footprint. Steel production according to IEA, has the second largest energy consumption of all industrial sectors, accounting with 22% of total energy uses and 31% of CO_2 emission [4]. Figure 2 shows the final energy demand of selected heavy industry and the CO_2 emissions, 2019.

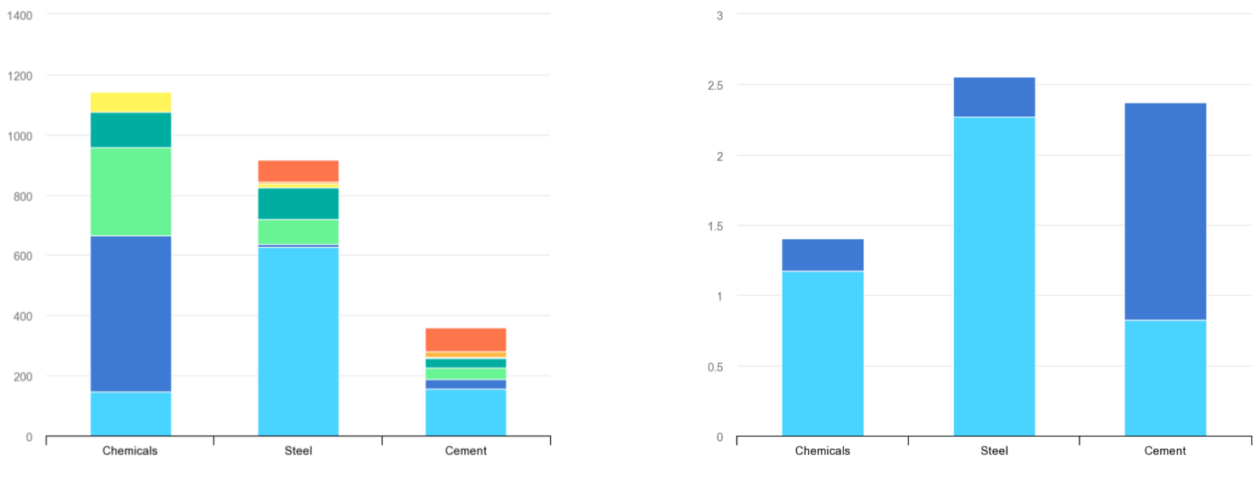

Figure 2 - Final energy demand and CO_2 emissions of selected heavy industry sectors by fuel, 2019 [5].

Mining by other hand, uses much less energy compared with high temperature processes and the energy use is concentrates on 3 few activities: grinding, ventilation, material handling, covering 80% of energy utilization [6]. However, mining activities have important local, regional, and global impacts, affecting people, biota, air, water and land uses during the mining cycle: exploration, construction, production and closure [7]. Refractories industry and cement have similarities based on processing of clays and carbonates using intensive energy consumption.

Figure 3 – Potential land and water impacts of mining activities.

3 – RECYCLING & TRANSFORMING WASTES INTO NEW PRODUCTS AND RAW MATERIALS

One of the best ways to save energy and decrease environmental impacts and CO_2 footprint on mining, metals production and civil engineering materials use is increasing the material efficiency during the life cycle management of products. Figure 4 presents the built Decision-Making Model for Recycling of Mining, Metallurgical and Materials Wastes (DM^2-$4RM^3W$) developed to improve the decision-making process related with recycling of industrial and mining wastes.

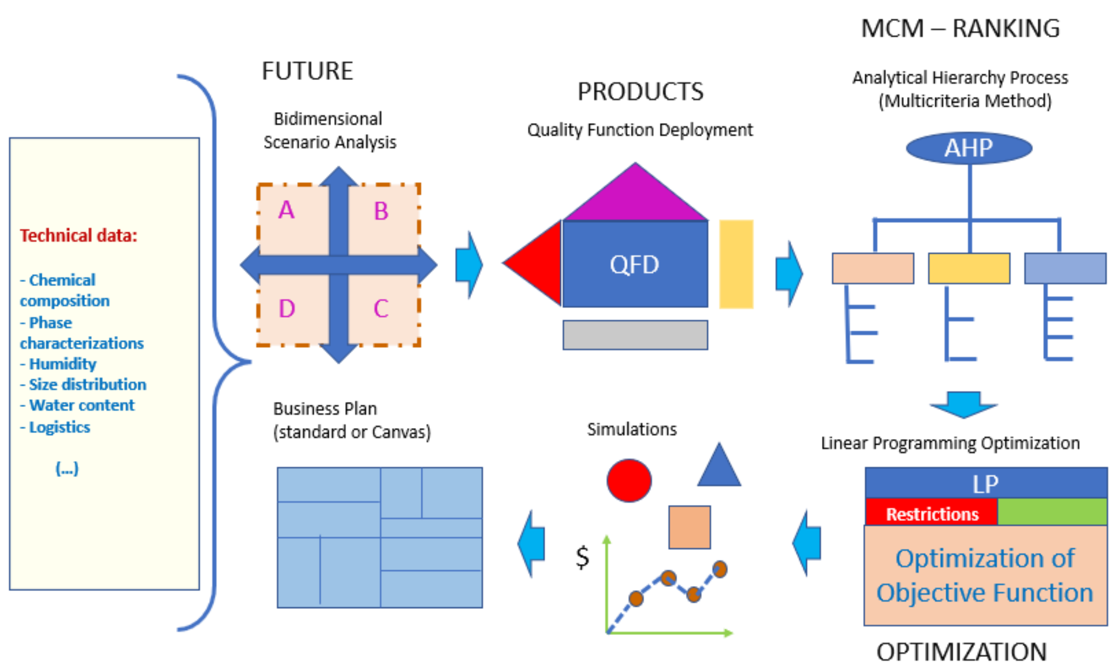

Figure 4 - Decision-Making Model for Recycling of Mining, Metallurgical and Materials Wastes (DM^2-$4RM^3W$).

The decision-making model aims to systematize the prioritization of choices, whether in the use of available raw materials (iron ore mining waste) or their allocation in the introduction into new products. The tools that determine the allocation of waste in products follow a hierarchy defined by technical criteria (technology), mass balance (stock, generation, and allocation in products/consumption), in addition to environmental, social, cost and logistics aspects.

The issue of costs will not be addressed directly in this analysis due to restriction and use of classified information's. Social factors will be evaluated qualitatively, as they would require local arrangements and the development of specific technologies that usually do not have an application scale consistent with the volume of material generated annually or even available in tailings dams. The model is based on several tools that combined could help the decision maker to have a broad view of recycling issue. Table 2 shows the combining of different management tools used in the recycling model.

Table 2 – Recycling model tools.

Tools	What	Information generated
Technical data	Complete characterization of each waste available.	Chemical composition, phase composition, size distribution, logistics aspects, humidity, mass generation, amount of material in dams, etc.
Bidimensional scenario analysis	Evaluations of 4 scenarios: focal question, driving forces, critical uncertainties, scenario framework, scenarios stories, implications and options, indicators, and signposts.	Overview evaluations of possible scenarios, based on independent uncertainties and long-range view: 5-30 years.
QFD: Quality Function Deployment	Systematics relationships between consumers desires (requirements) and engineering needs (technical aspects and properties relationships).	Customers product targets, technical requirements, technical assessments and customers assessments and competitive evaluation.
AHP: Analytical Hierarch Process	Analytical tool, based in pairwise comparations. The technique is employed for ranking a set of alternatives or for the selection of the best in a set of alternatives. The ranking/selection is done with respect to an overall goal, which is broken down into a set of criteria.	A reciprocal pairwise comparison matrix *A* is then formed using *ajk*, for all *j* and *k*. Note that *ajj*=1. It has been generally agreed that the weights of criteria can be estimated by finding the principal eigenvector *w* of the matrix $AW = \lambda max*w$; When the vector *w* is normalized, it becomes the vector of priorities of the criteria with respect to the goal.

Linear Programming & Simulations	Linear system of equations, representing the objective functions and model restrictions.	Indices and relative ranking of simulated solution of linear system.
Business plan Canvas	The Business Model Canvas is a strategic management template used for developing new business models and documenting existing ones. It offers a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances.	Principal factors: Purpose; Scope; Success criteria; Milestones; Actions; Outcome; Team; Resources; Stakeholders; Constrains; Users; Risks.

3.1 – AHP – RANKING OF RECYCLING MODEL VARIABLES

AHP was used to rank the model variables. All matrixial calculations was made by using the AHP-OS web platform [10]. The variables of recycling model were technology (tecnologia), environment (meio ambiente), logistics (logistica), social impact (impacto social) and economic impact (impacto econômico). Figure 5 shows the output values of variables priorities. The content and description of model variables is explained below.

Resulting Priorities

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

	Cat	Priority	Rank	(+)	(-)
1	Tecnologia	52.4%	1	14.5%	14.5%
2	Meio Ambiente	9.7%	4	2.3%	2.3%
3	Logística	11.0%	3	4.8%	4.8%
4	Impacto Social	6.7%	5	2.7%	2.7%
5	IMpacto Econômico	20.2%	2	9.3%	9.3%

Number of comparisons = 10
Consistency Ratio CR = 6.3%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4	5
1	1	5.00	5.00	6.00	4.00
2	0.20	1	1.00	2.00	0.33
3	0.20	1.00	1	1.00	1.00
4	0.17	0.50	1.00	1	0.20
5	0.25	3.00	1.00	5.00	1

Principal eigen value = 5.284
Eigenvector solution: 5 iterations, delta = 8.4E-8

Figure 5 – Ranking of model variables- input and outputs.

a) Technology: Aims to guarantee the solution for the application of the various wastes available, to introduce them as a source of raw materials in different formulations and applications (clinker, cement (composite), traditional ceramics, polymeric cements (mortars) and shaped ceramic products /cold extruded)), in order to maximize use, ensure operational safety, facilitate and make processing more flexible, minimize cost and maximize the cost-benefit ratio of the project.

- Ease/flexibility of handling.
- Development of high processing capacity processing route.
- Robustness and safety of technologies (efficient and proven technologies for processing high volumes of materials)
- Ease and flexibility of handling and processing

b) Environment: It aims to guarantee the solution for the application of the various wastes available, with low environmental impact (lower carbon footprint), reduce the use of non-renewable resources, minimize their disposal in dams or even guarantee the need not to build new dams of tailings, comply with environmental legislation, etc.

- Legal compliance (“compliance”): licenses, authorizations, laws, regulations.
- Use of stored waste (dams), etc.: metric, e.g., processing up to 500 Kt per year in dams, or consumption above the annual generation in order to generate demand for stored waste.
- Carbon payment due to the use of fossil fuels for movement/transport) of the material.
- Guarantee of zero stock of stored residues, in the new mineral processing plants.

c) Logistics: It aims to guarantee the solution capable of maintaining the supply and flow of materials throughout the year, flexible in relation to seasonality, capable of minimizing the transshipment process, minimizing costs.

- Minimization of modals.
- Minimization of transshipment operations.
- Minimization of logistical cost.
- Supply flexibility: definition of the scope of action depending on the market and generating source.

d) Social impact: Aims to guarantee the solution capable of interacting with communities with social vulnerabilities, so that the dismemberment of the solutions can be applied and have technology transfer capable of generating jobs, income and micro-entrepreneurship.

- Ability to foster employment and income generation in local communities.
- Assistance to a certain number of families, etc.

e) Economic impact: this variable will be calculated separately from the model, once the creation of a business plan is defined, using the company internal own methodology to define the cost of implementing the project.

4 – RESULTS

The recycling model generated a rank scale based on mathematical results of the utility index of new products. The output values of recycling model are shown in the figure 6.

Developed Products/Uses	Rank
Structural ceramics	58.74
Clinker	8.74
Composite cement	10.15
Composite cement (co-product)	4.21
Extruded ceramic	14.99
Polymeric mortar	3.17
Total	100%

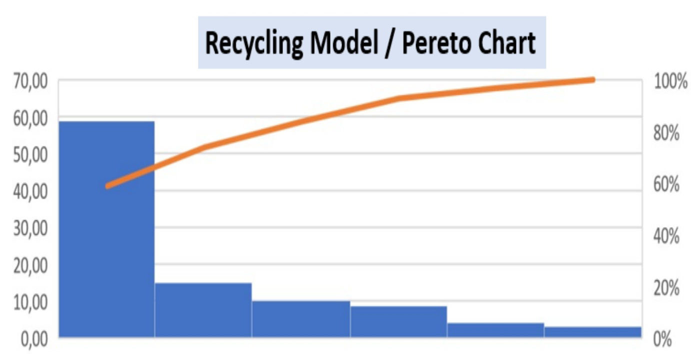

Figure 6 – Recycling model output – products developed using different types and amount of wastes into their composition.

5 – CONCLUSIONS

The recycling model based on multicriteria decision tool and quality attributes presented coherent and rational performance for ranking raw materials and products developed incorporating and transforming wastes in new formulations. The use of model for recycling mineral ore wastes, spent refractories and/or metallurgical slags bring advantages on systematic approach to valuate ESG input to increase environmental performance during the recycling of mineral and metallurgical wastes transforming it into new products.

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