Beyond the social license to operate: Whole system approaches for a socially responsible mining industry

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Abstract

The demand for minerals, metals and rare-earth elements is rapidly growing to support the transition to low-carbon energies, and the mining industry must increase its supply while facing complex Environmental, Social and Governance (ESG) risks. Traditionally relying on its engineering expertise to maximize ore extraction, the sector must now find ways to sustain its production while facing increased scrutiny from the public, civil societies and shareholders alike. The paper reviews current practice in sustainability assessment to highlight sector-specific characteristics and the notion of trust as central to effective project developments. Because the social interface of extractive operations is complex, dynamic and non-linear in nature, we recommend going beyond the aim of obtaining a social license to operate and use Systems Thinking to fully embed Corporate Social Responsibility (CSR) at the core of strategic mine planning. System Dynamics can foster interdisciplinary collaborations by bridging together social and technical flows within simulation models to identify sustainable levers of change. We present the development of a stock and flow model quantifying causal mechanisms between the use of cyanide, the environment, communities and public trust, and operational productivity. Industry practitioners, researchers and facilitators can use the model as an adaptable framework to engage with systems modelling in mining. We recommend its use in conjunction with meaningful stakeholder's engagement to ensure shared understanding, reduced uncertainty and long-term benefits for all.

Keywords: Corporate Social responsibility, Mining, System Dynamics, Socio-technical systems, ESG, Energy transition

1 The energy transition drives increased minerals demand and ESG risks

Securing a sufficient supply of materials and minerals is central to the diffusion of low-carbon technologies that will help alleviate climate change and sustain our future, yet this global challenge remains under-analyzed. As the Covid-19 pandemic hit mining operations and inspections globally, risks around the supply chains of renewables energies have come into sharper focus [1], and experts advocate that material security should be actively incorporated into formal climate planning to support the low-carbon energy transition [2]. The IPCC and the United Nations report that the amount of raw materials and metals required to build the devices and infrastructures demanded by a low carbon economy will be “substantial” and “immense” [3, 4]. The World Bank evokes the clean energy transition as “mineral intensive” and estimates that the production of the materials required could increase by no less than 500% by 2050, which represents more than 3 billion tons of minerals and metals needed to keep below 2°C of global temperature warming [5].

Such challenges place the mining industry at the heart of global efforts to respect the Paris Agreements and national commitments to Net-Zero carbon targets in the next decades. To sustain its production, help balance demand and unlock new reserves potentials, the mining industry has traditionally relied on its strong engineering expertise associated to rises in commodity prices to invest in exploration and technological innovations. However, the main social and environmental impacts of low-carbon technologies usually occur during the minerals extraction cycle [6], and research confirms that current prospective reserves are facing a very high proportion of environmental, social and governance (ESG) risks that are not directly linked to market prices [7, 8]. While the necessity to secure a solid social license to operate (SLO) from local communities is acknowledged by most large companies, growing concern and higher societal expectations over human-induced impacts on people and the planet have led to increased public scrutiny, and many shareholders now demand the mining industry to improve its ESG performance [9]. The Global Risk Perception Survey featured in the annual Global Risks Report shows that for the first time in 2020 “climate related issues dominated all of the top-five long-term risks” for businesses [10]. Recent catastrophes featured in the media such as the Brumadinho dam disaster in 2019 or the destruction in 2020 of the Juukan Gorge, an Aboriginal cave of particular archaeological importance, are also reminders that ESG issues can no longer be the subject of insufficient consideration [11]. This also shows that it is critical to acknowledge and address social and environmental concerns at the local level to support decisions and agreements taken at the national and international levels [12, 13]. The risks and challenges highlighted here suggest that improving extractions technologies with a rise in commodity prices will certainly be insufficient to ensure a sustainable supply of minerals into the future.

Unless the sector provides a sufficient supply of commodities, meet new expectations in ESG performance, and limit its very own contribution to carbon emissions [14], mining might actually impede rather than enable a fast and just energy transition [15]. The direction it will take depends on how the metal supply is governed over the next few years [2].

The sector can improve planning and risk evaluation – and better assess how it contributes to society - by capturing non-traditional operational values via more comprehensive approaches [16]. In particular, it is critical for mining companies to engage in collaborative, interdisciplinary methods and build long-lasting trust with their stakeholders. When efficient assessment tools are associated to genuine grass-roots relationships between companies and communities, project developments can create shared value and contribute considerably to the sustainable development goals (SDGs) [17, 18].

Current practices to assess sustainability in the mining sector do not always highlight sufficiently the systemic and dynamic nature of the socio-technical interface between mining operations, their communities and the rest of society. Similarly, extractive operations rely on techno-economic process modelling that does not fully embed social and environmental parameters; rather, sustainability and Corporate Social Responsibility (CSR) are still often considered as separate entities in planning processes. We think the industry requires a shift to tackle those challenges, and argue that using Systems Thinking methodologies operationalized through System Dynamics (SD) modelling is a step towards enhanced interdisciplinary approaches and accountability to CSR in mining. After reviewing sustainability assessment practices in the sector to highlight important mining-specific sustainability characteristics and the need for novel integrative approaches, we show how whole-system approaches, and particularly the philosophy of System Dynamics as presented by Sterman [19], are fitting to address mining's current major risks. We present the development of a generic simulation model quantifying for the first time interconnections between social and technical factors linked to chemical environmental contaminations. Specifically, we show that it is possible to represent together intangible parameters like community and public trust, and traditional techno-economic considerations such as the rate of ore processed, as quantitatively and dynamically connected within a single model. The model was created around the well-known existing tensions between the use of the notorious chemical Cyanide for metals recovery in Gold mining and public support. We propose that the adaptation of this practical model to similar case studies along with genuine stakeholder engagement can help industry practitioners embed CSR challenges at the core of their organizational planning approaches, improve transparency, and reduce risks and uncertainty. Similarly, the model can be of interest to scholars and facilitators as a tool to engage with systems modelling.

2 CSR and sustainability assessment frameworks in mining

Corporate Social Responsibility refers to the contribution of companies and their operations in achieving economic, social and environmental sustainability [20]. It is also understood as a set of ethics guiding businesses practices [21], which have been standardized under the well-recognized ISO 26000:2010 guidance [22]. A recent addition to the guidance shows how applying its principles can help companies directly contribute to specific sustainable development goals [23]. However, it has been argued that the application of the concept can be dependent on different corporations definitions of ethical conduct and their understandings of corporate and community relations [24, 25]. Notably, critics have accused certain multinationals to focus their CSR efforts on providing community services that actually contributed to dependency on the company and on the fluctuant level of resources allocated to CSR [21, 26]. Other authors see CSR achievements as a helpful resource to explore companies' attitudes towards their stakeholders [27]. The application of CSR is mostly established through the disclosure of environmental and social achievement in businesses' annual sustainability reports. Several international frameworks and assessment approaches were developed to support companies in implementing good practices and communicating on their CSR performances, and a few of them are dedicated to the mining industry. The Global Reporting initiative (GRI), which supports organizations disclosing information on their business's sustainability impacts, created a mining and metals supplement guidance in collaboration with the International Council on Mining and Metals (ICMM). The resulting reporting framework provides sector-specific KPIs for economic, environmental and social purposes that are "encountered more frequently or in greater measure than in other sectors" and that should be considered over the entire mine life cycle [28]. They encourage an integrated approach to minerals use and the main issues evoked include land management, contribution to economic and social development, and engagement with stakeholders.

Social life cycle assessments (SLCA) are a developing strand of the well-established Life cycle assessment (LCA) analyses, which are a standardized methodology of accounting for every environmental impacts of products components over their life cycle, to compare against environmental targets and avoid the "shifting of burden", e.g. displacing environmental impacts from an area of the supply chain to another. LCA mainly rely on inventories of physical quantities of the product system while SLCA requires quantitative and qualitative information related to geographic locations and impacts on stakeholder categories [20]. SLCA rely crucially on data collections and databases, but the relevance for the mining sector of such databases concluded that they provide mostly macro-level insights, preventing it to support studies for specific supply chains or at the company's or operational level [20].

Originally conceived as a tool for predicting the impact of projects prior to developments, Social Impact Assessments (SIA) includes the processes of "analyzing, monitoring and managing intended and unintended social consequences of planned interventions" [29]. They focus on how to identify, avoid, mitigate and enhance outcomes of a project for host communities [30]. They gradually encompassed different stages of developments, and the approach is recommended to be applied as an iterative process rather than only once at the beginning of the operations [29]. The International Association for Impact Assessment (IAIA) released a major guidance for assessing and managing the social impact of development projects [31]. A number of objectives have been highlighted as particularly important to pursue in SIA for resources developments, such as: considering all stages of the mine life cycle, leaving positive legacies, aligning community engagement with planning, building communities capacities, strengthening local partnerships, and keep management adaptive and flexible because of the changing and evolving nature of mine operations [30].

The responsible Mining Foundation publishes a bi-annual Index providing an evidence-based assessment of large-scale mining companies' policies and practices on a range of economic, environmental, social and governance issues, based on publicly available information and from the perspective of current society's expectations [32].

In similar lines to the LCA and SIA which considers several stages of a product or project life cycle, frameworks developed in the last decade by major international organizations go further than KPIs reporting by linking ecosystem services and the societal interface to business goals over the mine life cycle. They propose to develop strategies based on boundaries selection and the identification of dependence and causality [33, 34]. After reviewing such frameworks, Lechner et al. proposed a 5 step iterative method of assessment focused on cumulative regional impacts, and advocated for further efforts to develop novel, integrative modelling efforts encompassing the environmental and social impacts of mining [35].

Most recently, the concept of "natural capital" has gained traction as a way to acknowledge the importance of the natural environment on economic and social well-being, and is likely to become part of decision-making processes within governments and industries [36]. Noteworthy contributions to create an assessment framework include that of Bateman and Mace [36] and the "NCIF" of Fairbrass et al. [37]. Their approach consider and encompass more comprehensively feedback flows and human-induced inputs and outputs over time, which present promising prospects of adaptation to the mining sector and could be complementary to the System Dynamic methodology presented later in this paper.

Lastly and importantly, a very well-known concept intertwined with CSR in Mining is the social license to operate. The notion traditionally reflects issues related to public acceptance of mining, and has become very popular in the industry in the past decade, where it has slowly evolved to encompass the evolving nature of the relationships between industries, communities and stakeholders [38]. The notion has been criticized by Owen and Kemp [39] as having been used as a traditional risk-oriented approach failing to help companies engage more with their stakeholders, build trust and restore the lost confidence of impacted communities. While the assessment frameworks presented in this section have brought tremendous improvements to CSR accountability and reporting over the two past decades, the discipline is still largely considered as a separate entity to traditional, shorter term techno economic perspectives to mining project developments. Moffat and Zhang's work on understanding the paths to community acceptance confirms that long-lasting trust alongside the mitigation of operational impacts is crucial for mining companies to obtain and maintain their SLO [40]. This proves again the importance of linking the implementation of CSR and SLO approaches to building mutual respect and trust, and the need to develop more studies and frameworks that can facilitate understanding and dialogue between the industry and its stakeholders. In the next section, we explore the theorization of trust in natural resources management and connect it to the notions of mining community and public trust considered in this study.

3 Theorizations of trust and relations to the mining interface

The natural resource management literature explores, amongst other, the long-term consequences of industrial operations on surrounding landscapes. The field recognizes the importance of people's interactions with their land, the value that can be harnessed from their expertise, and contains interesting theorizations of the intangible value of trust. Notably, trust has been highlighted as a driver of collaboration and conflict resolution [41] and as such is identified as a major component of natural resource management processes and their outcomes [42]. Stern and Coleman highlighted that the notion remains relatively underexplored and proposed four categorizations of trust relevant to collaborative management in the field: dispositional trust, rational trust, affinitive trust and procedural trust [43].

In mining and in the present study, "community trust" is mainly considered as an evaluation of the mining operations performances against initial expectations. Under their framework this is most closely related to rational trust, which is "based primarily upon expectations of reciprocity or perceived utility in strategic interactions", or "based on evaluations of expected outcomes of a relationship" [44]. However, the community trust is likely to have a different initial value depending on the area where operations take place, as for example, high local expectations of employment can lead to a higher initial rational trust but deplete quickly in case of incidents or if expectations are not met. In areas where new projects development do not present immediate local advantages, communities could present an "affinitive distrust" which could act as an immediate barrier to developments, even more so if a notorious chemical is used, because of possible perceptions of "incompatible values between two entities" [44]. The evolution of the wider public trust over time can be most closely related to the "affinitive trust", which assessment depends on the perceptions of the integrity of the trustee and on assumption of shared values, which can be reinforced by the type of media coverage received by the company piloting the mining operations. This type of trust has also been previously designated as a "social trust", a term that has been employed slightly differently by other authors to express a "general willingness to rely on those who have the responsibility for making decisions" [45] [46].

While Stern and Coleman recognize the difficulty to create a "one size fits all" strategy, they highlight elements likely to enhance participants' trust in procedures and reduce uncertainty between stakeholders, including participatory developments, transparency in decision-making processes, as well as an attention to distributing equitably benefits and risks [47, 48]. Eventually, Stern and Coleman suggests that such undertakings in process developments can lead to a form of "procedural trust", where a greater degree of confidence in the compliance of others arises. In the next section, we show that Systems thinking methodologies are aligned with this vision to reduce risk by developing a common sense of purpose amongst stakeholders, and hold particular potential to represent and address the socio-technical problematics faced by Mining.

4 SD as a solution to represent socio-technical complexity in mining

4.1 The dynamic nature of extractive operations

The mining sustainability characteristics highlighted in the literature shows that the dynamic interactions arising at the interface between mining, the environment, host communities, and the wider socio-economic context often create exceptionally complex systems.

Lechner et al. point out that the temporal and spatial aspects of mining operations such as irreversible land alteration, social impacts, public scrutiny and the cumulative nature of those impacts, are just some of the challenges faced by mine operations [35]. Mineral resources are subject to boom and bust cycles due to volatile commodity prices [49], leading to periods of expansion and high production to reduced or halted operations. These cycles are often not felt in the same way or on the same timescales by the different stakeholders tied to mine operations throughout the mine life. Expansions can provoke substantial effects on host communities who sometimes have long-term generational ties to the site. As Kemp et al. suggests, "accepting the dynamic nature of social risk is a major conceptual hurdle for the industry in defining the relationship between its own activities and social issues"[50]. By looking beyond traditional planning methods to understand the underlying structure of those systems, and considering interlinked risks both "from" and "to" their operations, the sector has the opportunity to capture important aspects of the business that are often neglected, and tailor management responses accordingly [18]. It is extremely difficult to apprehend every possible feedback dynamics within a complex system because of the large number of parameters involved, which affect each other's over different delays. Such systems have non-linear behaviors over time, meaning that changes in input can lead to unintended consequences throughout the workings of the system, a phenomenon also expressed as "the counterintuitive behavior" of systems [19]. As a result, attempts to stabilize such systems may destabilize them, leading to "policy resistance", i.e. the tendency for interventions to be delayed, diluted or defeated by the response of the system to the intervention itself [51].

4.2 Systems Thinking and System Dynamics

The discipline of Systems Thinking (ST) follows the principle that a system is more than a collection of its parts [52] and involves the ability to represent and assess dynamic complexity [53]. Arnold and Wade refocus the purpose of ST as aiding in solving systemic problems, and explicit the concept as "a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects" [54]. ST is related to the concept of "whole systems" approaches, increasingly acknowledged by academic and government bodies as critical in tackling society's current and future complex challenges [55]. Systems thinking has been historically divided between "hard ST" which tackles well defined engineering problems, and "soft systems methodologies" (SSM) suitable for "ill-defined, messy, or wicked problems" in which "users learn their way from finding out about a situation to taking action to improve it" [56]. However according to Checkland the real distinction lies in the fact that SSM recognizes "the systemic and complex nature of any process of inquiry and decision-making into problematic situations" [56]. SSM considers indeed that the complexity of real-life problems is also affected by "multiple interacting perceptions of reality", i.e. by the different assumptions people have on a similar issue [56]. As a result, soft system methodologies do include the systemic and complex nature of actors, decisions, and intangible societal factors.

System Dynamics is a modelling method based on Systems thinking, inclusive in essence of the SSM principles. A comprehensive review of SD and SSM has been written by David C lane and Rogelio Oliva

[57], and a guide on Systems approaches to managing change has been edited more recently by Reynolds and Holwell [58]. SD was created at the Massachusetts Institute of Technology by Professor Jay W. Forrester in the mid-50s, and initially developed for the industrial and engineering sector [59]. It then opened to urban dynamics and, after Forrester was invited by the Club of Rome to present his work, had a breakthrough in global environmental systems with “World Dynamics” [60] and Donella Meadow’s “Limits to growth” [61]. The model representing the stresses placed on the Earth’s carrying capacity was updated in “Beyond the limits” [62]. The method was subsequently presented in detail in “Business Dynamics” [19] in which Sterman stresses the importance to include “intangible” and so-called “soft” values in corporate decision-making. SD models are intended to observe the behavior of systems over time, and are based on causal flows, feedback loops and delays which emphasizes the reinforcing or balancing feedback mechanisms between variables. Flows represent the rate of change of a stock X over time (dX/dt), and models use numerical and graphical integration over time, making them accessible to a wider range of stakeholders [63]. While models can become very complex, they are based on a disaggregation of simple causal relationships between elements, enhancing transparency and overall understanding [64]. Another important concept is that of “mental models”, which is related to the “perceptions of reality” highlighted in SSM. Forrester already stressed in 1961 that all decisions taken by human beings are based on “beliefs” and “assumptions” about causes and effects forming the network affecting whole systems, but also on the boundaries of the system and the time horizon considered as relevant to the issue at stake. Making this concept part of the modelling process and taking into account a breadth of stakeholders’ perceptions in planning management can be pursued to enhance collaborative and participatory approaches and improve trust in project developments [65]. Ultimately, the purpose is to provide accurate and practical insight into multi-faceted problems needing appropriate decision-making and tailored policies [66].

The method recommends taking into account in models intangible and non-monetary notions like trust, values, and attitudes, which can have a significant influence on decision-making and project outcomes. These notions can be difficult to quantify (lack of appropriate units), or to assign a value to (perceptions can differ), while another common challenge is data scarcity, when data are not monitored regularly or with standardized units. While SD models must be populated with as many reliable data as possible, the approach offers flexibility with such challenges, proposing to rely on estimates, value scales and participatory modelling to elicit knowledge, rather than ignoring altogether such important factors. It then focuses on offering a better comprehension of the feedback mechanisms and delays influencing the systems’ behavior over time, highlighting potential levers of action towards a desired outcome. The flexibility and comprehensiveness of the approach is in line with the SIA recommendations dedicated to the resources sector, and can provide significant additional advantages to frameworks focused mainly on sustainability indicators. SD therefore holds potential to help the mining industry address major socio-technical challenges, offer comprehensive insights into future pathways, and help reduce risks and uncertainty along the Mine life cycle stages.

4.3 A field gathering interest

The relevance of SD to inform sustainable decision making, notably at the local level, has been proven in various sectors. Examples include improving governance, engagement, strategic adaptation and resilience with coastal communities [67-69] or the analysis and development of policies in illegal logging and fishing [70-72]. There is also interest in using SD to strengthen SIA [73]. Led by the momentum on “whole-systems” considerations and in a bid to enhance traditional techno-economic oriented modeling and scenarios, SD is also gathering increasing interest in socio-technical transition research [74] and socio-technical energy transition modelling [75, 76]. Research using SD applied to the mining sector is still emergent; recent studies have shown it is a promising tool in understanding and addressing complex interactions such as environmental impacts, price, and resource supply in dynamic markets [77, 78]. Of particular relevance, Sverdrup and Olafsdottir explored the flows of mercury from geological sources through to society and the environment on a global scale [79]. They highlight losses at different stages of the production and human exposure, but do not go into operation-level details on wider societal perceptions and support for mining. The authors confirm the scarcity of studies in the domain while highlighting that traditional econometric models "generally lack system feedbacks". Few other studies so far have used modelling approaches to examine social or environmental dynamics in mining; however, we found a growing interest in using SD to explore green mining construction policies [80], behavior-related coal mine safety [81], interactions between environmental and economic factors [82], critical material supply [83, 84], and impacts on resources and the environment [85], while Boateng [86] uses Agent Based Modelling (ABM) to specifically explore the community acceptance of mining. Those promising researches shows the methodology is gathering interest in the sector, and that further investigations with a particular focus on ESG factors considering the increasing complexities of the mineral production systems are required to unlock the full potential of SD to improve mining's sustainability performance.

The empirical review conducted by Mancini et al. [20] demonstrates that "land-use related impacts and impacts affecting human health and human rights appear to be the most concerning social aspects in the mining sector". In order to contribute to the representation of such issues in modelling, while encompassing the most important notion of trust and engagement highlighted by the literature on CSR and natural resources management, we created an adaptable simulation model linking the use of cyanide in leaching operations to potential environmental contamination, community and public trust, and operations productivity. By bridging together technical, environmental and social considerations, our study aims to contribute to accelerate the use of SD, multi-stakeholder engagement and collaborative decision making in mining, to improve analyses and knowledge in a context where society aims to balance the priority of long term climate mitigation with social and environmental justice concerns [87]. In the next sections, we present the methodology and steps followed to create the stock and flow model and its user's interface.

5 Model creation methodology

After engaging with the literature to highlight essentials concepts in addressing environmental and social challenges in mining, we followed the System Dynamics modelling approach as detailed by Sterman in “Business Dynamics” to develop a problem articulation, a dynamic hypothesis and a stock and flow model [19]. The model allows the visualization and simulation of a recognized socio-technical problematic in the gold mining industry and can be used as an adaptable framework to case studies of any type of environmental contamination affecting health and safety, social welfare, community trust and the company’s public image. A user interface has been developed to enhance the possibility for industry practitioners to engage with the methodology and action potential levers of change. The details of the feedback mechanisms themselves requires the exploration of the model flows. The model and user interface were created with Stella Architect professional 1.9.2, and they have been made available online on the ISEEE Exchange platform [88], for transparency, reusability and transferability purposes. The full documentation for the equations, modules and stock and flows is also available online [89]. As our topic deals with social concepts rooted to human cultural values, we aim to respect the main principles of Soft Systems Methodology as developed by Checkland [56], which puts the emphasis on the sharing of perceptions and worldviews between different groups of stakeholders. The modelling focusing on the technical side of the operations was primarily backed up by industry reports on leaching operations and chemical management standards such as the international Cyanide management code [90, 91]. The environmental, social and wider societal considerations included are highlighted by the literature on social impact assessment and natural resources management. In addition, the prototype was created in a multi-disciplinary institute composed of six centers dedicated to environmental management, mine production and processing, social responsibility, geology, water, and safety in the minerals industry. Researchers from three of these centers were invited as contributing authors of the model and the present paper. Three additional seniors researchers have been consulted specifically for their expertise on the social interface of mining, cyanide management protocols, and System Dynamics modelling. Their input allowed the appropriate and reasonable quantification for the valuation of initial stocks values for both tangible and intangible variables, cyanide related characteristics, and delays affecting flows and rates of change. While we linked earlier in our study mining community and public trust presented in the model to the possible different categorizations proposed by Stern and Coleman [43], we kept in this first version a unidimensional interpretation in line with statistical analyses by Vaske et al. suggesting that multiple dimensions of trust may be difficult to separate [46]. This is because the model represent the notion of trust for the first time as part of the mining socio-technical interface in a dynamic model, and is meant to stay easily adaptable to other contexts.

6 Creation of the socio-technical prototype model and interface

6.1 Problem articulation and dynamic hypothesis

We present in this section the steps followed to create a generic model centered on the main causalities between the use of cyanide, potential toxicity in the environment, H&S, and trust in mining operations. In SD, it is important to articulate modelling around a particular problematic to address, rather than attempting to model a system, in order to focus on finding ways to forecast and mitigate the specific issue at stake. Boundaries are delimited to ensure that the most important variable having a reinforcing or balancing influence on the problem studied are represented. According to the review by Mancini et al [20] highlighting land-use impacts affecting human health as one of the most concerning social aspects of the sector, we articulated our problem definition around environmental health and safety and extended it to include the notion of trust highlighted in previous sections as paramount to promote shared understanding and support project developments.

A well-known problematic in mining, but that hadn't yet been represented in a dynamic model, is the social effects tied to the use of cyanide in gold leaching operations. A recent illustrative example is the leaking of a million liters of cyanide solution into nearby rivers from the Barrick's owned Veladero gold mine in Argentina in 2015, which highlighted already brewing social tensions and a lack of trust from local residents in official announcements [92]. This led to a temporary suspension of the operations, a fine of $9.8 million, ongoing concerns from the local community, and technical maintenance orders from local authorities. Additional spills followed in March 2016 and September 2017, leading to further health concerns and new temporary closures and restrictions [93].

The problem addressed by the model can be defined as follows:

90% of operations processing gold worldwide use cyanide leaching to recover the precious metal from the ore. The process is mostly well managed in large operations, but often triggers concerns because it has the potential to contaminate water from uncontrolled cyanide releases and cause direct and indirect impacts on biodiversity and local communities. Therefore, the process is tied to inherently complex causal relationships related to engagement, legacy, ethical and reputational considerations.

The main feedback loop is the balancing effect between the use of the chemical and trust felt by the community and the wider public in the operations. While the likely behavior of the value of trust over time depends largely on the local context under study, we assume a tendency of "overshoot and collapse" (exponential increase followed by a sharp decrease) in areas with high development expectations and in case of major incidents happening, and a "goal seeking behavior" (slower gain of trust before reaching a stable state) otherwise.

6.2 System boundaries and presentation of the modules' functioning

The model features six modules: leaching process, tailings, risk of incidents, environment, community health and safety, and community and public trust. Mining operations are represented by the leaching process and tailing facilities. A risk probability that an incident could happen per time step determines the amount of cyanide potentially released – involuntarily - to the surrounding environment. The resulting consequences influence the level of community H&S which itself determines, amongst other parameters, the level of local community and wider public trust. In turn, trust has the potential to affect positively or negatively the tons of ore processed, affecting the normal continuation of the operations.

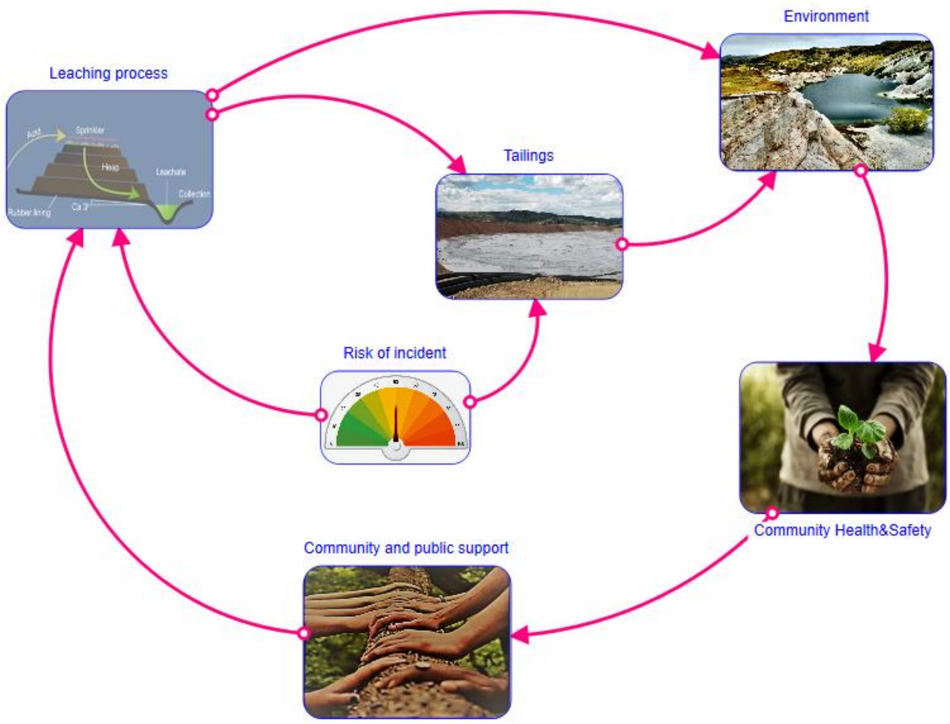

Figure 1: Resulting high-level model overview in Stella

All stocks featured in the model are accumulating or decaying over time through the numerical integral equation: Stock (t) = INTEGRAL (Inflows – Outflows, Stock t0). For readability, the stocks detailed in the sections below are represented with their “equivalent” differential equation representing the Net change in stock = d(Stock)/dt = Inflow (t) – Outflow (t). All equations and further details on the modules are accessible online [88, 89].

6.2.1 Leaching process, Tailings and Risk probability

This sector represents a simplified heap leach process with a focus on the stock “quantity of cyanide (CN) in current use”. This stock is a function of two input “inflows”, first the new cyanide entering the process per time unit, and then the cyanide recycled into the process with a delay (1). The value of the inflows depend on the tons of ore processed, on the concentration of cyanide required in the leaching solution and on the percentage of cyanide reused. Apart from the CN that will flow out of the process to be re-used, two other outflows represent the amount of cyanide leaving the process to tailings and the amount potentially lost in the environment either in normal functioning or in case of an uncontrolled incident (2). The occurrence of incidents is determined by a binomial function with a risk probability which is connected to the module “Risks of incidents”. Two additional stocks help define the quantity of water and of ore that are also going through the leaching process and will eventually feed into the tailings total volume. The productivity of the operations in this module, i.e. the tons of ore that the operations will be able to process, is affected by a multiplier effect that will be determined and fed back from the module evaluating the level of trust and support that the company can benefit from.

Net change in CN in use in the leaching process, in tons: d(CN in use in leaching)/dt =CN entering leaching(t) + CN returning to leaching (t) – CN to be reused (t) – CN lost to the environment – CN going to tailings (t) (1)

*CN lost in the environment from leaching in tons/month: IF (Incident =0) THEN (percentage lost in normal functioning*CN in use in leaching) ELSE (percentage lost if incident*CN in use in leaching) (2)*

The tailings' volume is determined by an inflow linked to the amount of CN, water and spent ore that has been sent to the tailings, minus the amounts re-used for leaching or lost in the environment. An exogenous variable allows to adjust the volume by adding any other release to the tailings in the same period, and, similarly to the stock representing cyanide, it is possible to specify what amounts or percentages can be reclaimed, released voluntarily in the environment after appropriate treatment, or lost in normal functioning and in case of an incident. To determine a risk probability that will influence the amount of losses in the environment from the leaching and tailings modules, we calculate an average performance in infrastructure maintenance, which comprise qualitative scale valuations of the quality and regularity of maintenance checks, the compliance to regulations,, and the overall condition of the infrastructures. A graphical function is then used to translate the average performance (x- axis) into a probability of incidents per time step (y-axis) following an exponentially decreasing curve.

6.2.2 Environment and community H&S

The "ecosystem" represented in this sector is a bounded water system, which volume evolve according to the quantity of materials released from the operations, and by exogenous variables that allow for additional inputs and a percentage of evaporation per unit of time. The main stock of interest however, is the CN concentration in the ecosystem (3), which corresponds to the total CN quantity voluntarily or involuntarily released from leaching or the tailings facilities, divided by the water system volume. The concentration of CN coming from the flows that are voluntarily released from the tailings after treatment should be different than those that are lost during incidents. However, both should be impacted by whether the operations are in compliance with environmental protection agencies (EPA) regulations, and so it is possible to "tick" this option in the model and in the interface. If the operations are indicated to be in compliance with the local EPA, then the maximum legal level concentration applies; if not, a concentration measured on site or the closest estimate should apply. All units are adjusted to be consistent with the CN concentration in the environment represented in g/tons (ppm).

Net change in CN concentration in the environment in g/tons: d(CN concentration in the environment)/dt=Increase in contamination (t) – Chemical decay or removal(t) (3)

The toxicity level (4) represents how many times the CN concentration in the environment reaches or exceeds the official toxicity threshold [91]. We assume in this prototype that the community has direct exposure to the ecosystem. A graphical function determines the effect the toxicity level is likely to have on the "initial or usual H&S" of the local community. For a level below 1, the effect is neutral. From 1 and beyond, a negative multiplier affects the initial H&S to deliver an actual H&S (5) that steadily decreases and will reach zero closer to a toxicity level of 2 (twice the value of the toxicity threshold). In the current scope of the study, it is considered that operations would not start if the initial community H&S was below 5.

Toxicity level (Dimensionless): CN concentration in the environment/max carrying capacity (toxicity threshold) (4)

*Actual community H&S ranking (Dimensionless 0-10): Effect of toxicity on health*Usual health ranking (5)*

6.2.3 Community and public trust

The level of community trust is determined by the H&S ranking and the company's performance in community engagement (6). As trust is a value that is hard to gain but easily lost – especially if people are directly affected - its theoretical value is completed with a goal-seeking stock representing more accurately a likely "actual" trust. This stock is defined in such a way that, while aiming to reach the calculated trust, it is impacted by a longer delay when increasing in value, and a shorter delay when decreasing (7). This captures the natural behavior of a long lead time when gaining trust, and the potential to lose trust quickly. The structure is similar for the general public trust, which is determined by the ranking of community trust and the company global image through media coverage. However, the delays affecting changes in trust are shorter and less disparate here because the wider public is not directly affected. Their trust is rather "perceived" and built mostly on external sources (general media, civil societies' coverage, global company image) (8). Depending on the level of media coverage of local communities concerns, the community trust will account for ½ or 1/3 of the wider public trust.

The average of local community and public trust rankings is then connected back to the productivity of the operations through the "effect of average trust on project's productivity", a graphical (curve) function that determines a positive or negative multiplier effect on the tons of ore processed in the leaching operations (Figure 2).

Engagement performance: (sense of inclusion in decision making + perception of planning process fairness + transparency + cohesion in the community) /4 (6)

Variation in community trust (biflow): IF gap between calculated and actual trust > 0 THEN gap between calculated and actual trust /delay to increase ELSE gap between calculated and actual trust/delay to decrease (7)

*Calculated Public trust (0-10): IF Media coverage of communities concerns > 4 THEN (Actual community trust + Company image)/2 ELSE ((Company image*2) + Actual community trust)/3 (8)*

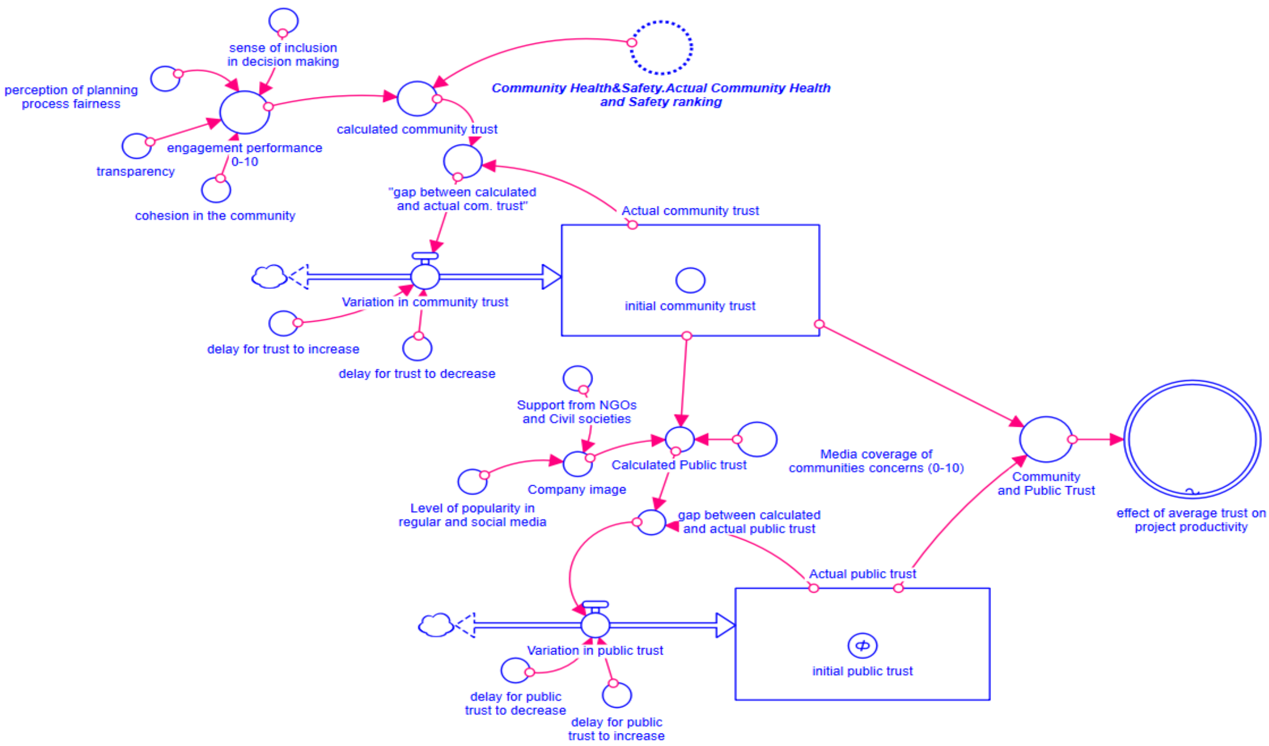

Figure 2: Determining the intangible value of trust

6.3 User Interface

The user interface available on the ISEEE Exchange platform provides general information on the problematic addressed and offers three "dashboard" action panels. The main panel features selected socio-technical actionable levers and graphical results (Table 1&2, Figure 3&4), while two additional pages allow actions on further social or operational-specific parameters.

Table 1&2 shows a selection of the levers, or external inputs, that users can modify in order to observe indirect impacts on the system's behavior, i.e. on the evolution of the main variables of interest over time. These selected observable results shows likely impacts on the environment, on safety and trust, but also on productivity. There is no direct single link between levers and results, as the levers influence several variables and flows that are endogenously calculated throughout the model.

Levers
Concentration of CN in leaching solution (ppm or g/tons)
Compliance to EPA regulations concerning CN concentration in tailings (Yes/No)
Level of performance in operations maintenance (0-10)
Transparency (0-10)
Local community sense of inclusion in decision-making (0-10)
Company popularity in media (0-10)
Regularity of maintenance checks (0-10)
Condition of infrastructures (0-10)
Leaching solution/ton (ppm)
Chemical decay (months)

Table 1: Main actionable levers

Observable results over time
Tailings volume (tons)
Tailings volume lost in the environment (incident) (tons)
Cn concentration in the environment (ppm or g/ton)
Toxicity level (0-2)
Community H&S (0-10)
Community actual trust (0-10)
Public actual trust (0-10)
Ore actually processed per year (tons)
Effect of trust on tonnage (0-1.3)
Company image (0-10)

Table 2: Main observable results

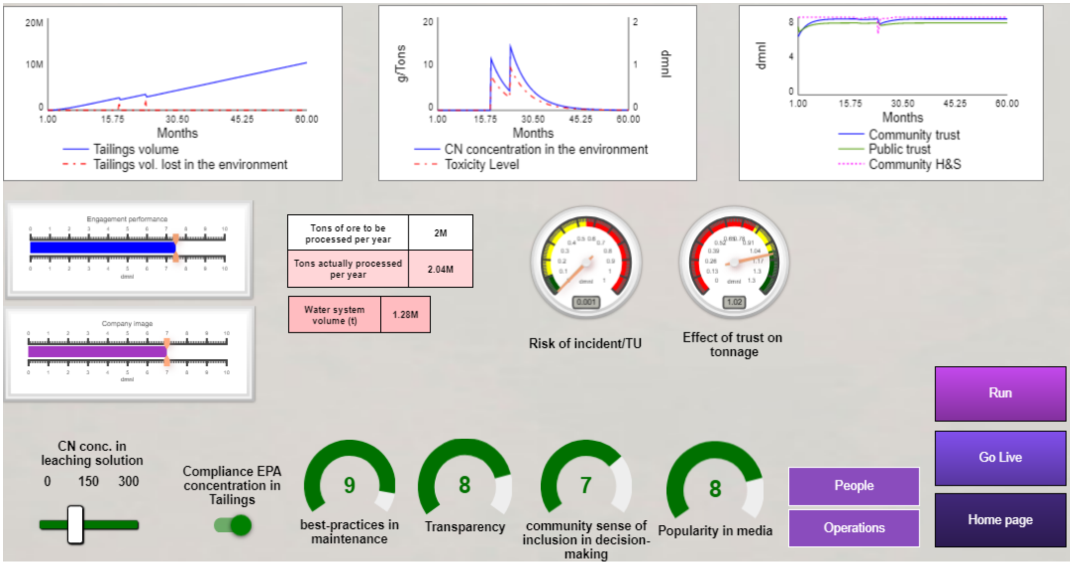

Figure 3: Simulation results over five years with good average performance

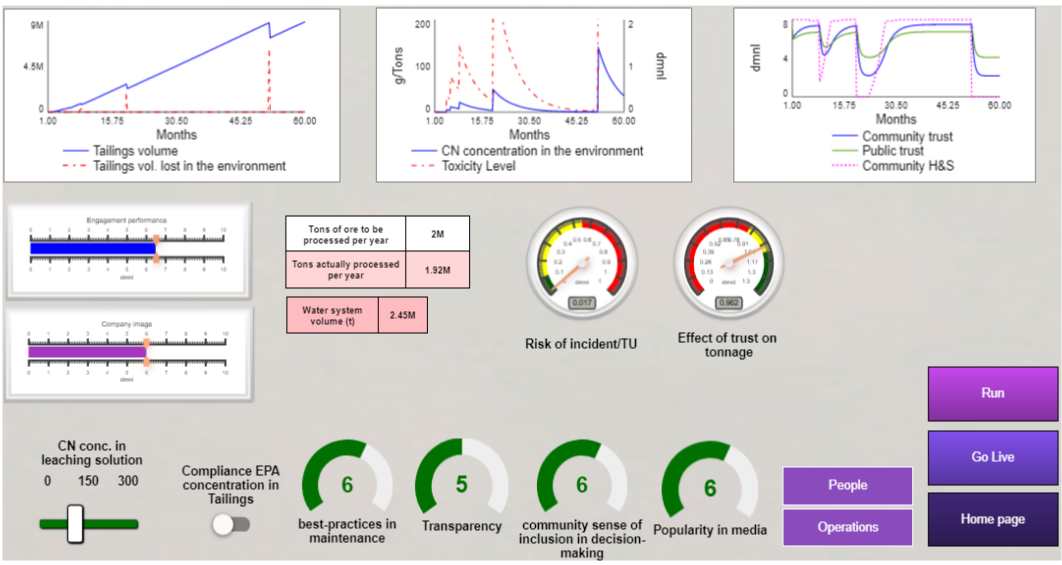

Figure 4: Simulation results over five years with poor to medium performance

The model was thoroughly tested for units and equations consistency and mass balance (testing for any anomaly in stocks inflows and outflows). The model settings in Figure 3 and 4 are:

Time Units: Months; Stop time: 60; Delta time: ¼; with Euler integration

These are set to observe a detail of the system dynamics for five years from the start of the operations. Eventually the model can be set to observe the entire mine life cycle. If time units are to be changed to years, the variables that are set to specific units of time throughout the model must be updated accordingly. Examples of simulation results can be observed in figure 3 and 4, where general trend behaves accordingly to the direction taken by the company in enforcing sustainable approaches and cultural engagement. While incidents may always happen, following best practices in maintenance and a strict compliance to concentration levels in the tailings facilities can significantly improve chances to avoid the worst in environmental health and safety and anchor an overall steady community and public trust. As a result the company is in a better position to perform as planned, or slightly better than expected, over the studied timeframe (Figure 3). On the opposite, increased instability and unpredictability can be clearly observed when poorer socio-technical performances are observed on average (Figure 4). It is important to note that simulations with similar inputs may return different results as the risk probability featured in the equations calculating amounts lost to the environment introduces a random factor, representing possibility for real-life unplanned external-induced incidents.

7 Analysis and Discussion of future research

The model allows a rapid overview and understanding of the wider socio-technical problematics tied to the use of potent chemicals in mining, and can be used as an introductory approach to collaborative research looking into specific case-study operations. To enrich technical, environmental and cultural details, adaptations and extensions of the model would benefit from the inputs of a diverse range of stakeholders, which can help participants visualize explicitly the causal links and feedback mechanisms at play in the difficulties they experience. In this current form, the dashboard is primarily intended for industry practitioners, to see the possibility to quantify evolving socio-technical factors within a single model and sensitize them to the need of including CSR in a systemic, embedded way in their modelling rather than as an external risk. Possibilities of academic or business further developments also include the adaptation to other chemicals characteristics, creating links to wider economic and market related factors, or even including international governance and global shifts in societal values and expectations.

The accuracy and levels of insights generated by the simulation results could be improved by a number of additional options and details. Several timescales could be featured to observe independently different stages of the mine life cycle, like observing the behavior of trust from the exploration stage, or help the study of post-extraction human-environment landscapes to complement innovative studies such as [13]. The representation of trust could be further improved so that an accumulation of incidents would lead to building even longer delays to build back trust, but also to include the different categorizations of trusts by Stern and Coleman discussed in earlier sections [43]. Notably, the notion of “distrust” could be added, as being more than a simple lack of trust, to detail the potential concrete “responses” from the community and the public leading to decreased productivity for the operations. The percentage of loss of chemicals in normal functioning and in case of an incident are currently left exogenous because valuations would depend largely on different case studies’ characteristics, but they could be naturally linked to the performance in management and endogenously calculated within the model. Similarly, data informing the risk probability of incident could be further explored: will a poor infrastructure maintenance increase mostly the occurrence of incidents, or their seriousness? In order to allow practitioners explore the potential improvements made by changing some aspects of their practices, there is currently no feedback loop detailing how the company can perceive the decreased productivity and automatically act on improving the environmental management, but this could represent an important area of further research. Similarly, while the most important way to include “perceptions” of the world by different actors is through collaborative modelling, it is also possible and relevant to quantify within models some variables as they are perceived or interpreted. This concept is touched upon in the case of the public image of the company, which is a public perception of the trustworthiness of the organization, influenced by media coverage. Further variables and dynamics that could be included are, for instance, actual impacts versus perceived impacts, delays in acknowledging releases, mistaken interpretations by media or the public, etc.

Finally, while it is not possible in the user interface to modify variables that are tied to endogenous calculations within the model (as this could affect the workings of the system), a large array of parameters could be added for observational and discussions purposes, such as the initial value for every stock representing intangible values and quantities.

8 Conclusion

The Mining sector must ramp up its production to supply the significant amount of materials required to transition to low-carbon energy systems. In the same time, ESGs risks and societal expectations are rising rapidly, reflecting complex local contexts, increasing public scrutiny, and a demand for more accountability by investors. We reviewed well-recognized frameworks to Mining CSR assessment to elicit the most important characteristics of the social interface of mine operations, with a special focus on the notion of trust, key to project developments outcomes. Because of the complex, interconnected and dynamic nature of the socio-technical characteristics of the extractive industry, we then propose that they could be best addressed by engaging in Systems Thinking and System Dynamics approaches. The methodology is articulated around the representation and understanding of causal flows, feedback loops, and delays, which allow observing dynamic behaviors over time and identify potential levers of change. It offers the possibility to create quantified models that can rely on both “hard and “soft” data so as to not overlook any aspects of the problem at stake, while highlighting areas where further empirical research is crucial.

We created a simulation model which for the first time represent together social, technical and environmental factors linked to the use of cyanide in gold leaching processes, potential impacts on environmental health and safety, and people trust and support in the continuation of the operations. A user interface allows actions on different socio-technical performances (e.g. technology, infrastructure’s maintenance and community engagement) and observe potential outcomes over time (e.g. losses in the environment, communities and public trust). The model is adaptable to several contexts and chemicals, and can be used as 1) an help for industry practitioners, to engage with systems approaches, embed CSR issues at the heart of their planning, and improve transparency 2) an adaptable framework for researchers, to model potential environmental contamination case studies 3) a facilitation tool, to engage with systems thinking and interdisciplinary modeling in mining.

This research contributes in particular to a gap in quantifying and modelling important qualitative environmental and social narratives in operations planning and strategic decision-making in mining. The full potential of systems methodologies can be harvested when applied with genuine multi-stakeholder engagement, to create a common sense of purpose and reduce risk and uncertainty. In this way, the approach proposed in this paper can lead to the creation of what Stern and Coleman call “procedural trust”, where a greater faith is placed in the compliance and legitimacy of others.

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