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Série Estudos e Documentos

Sustainable Indicators for the Extraction Minerals Industries

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CETEM
CENTRO DE TECNOLOGIA MINERAL
Ministério da Ciência e Tecnologia

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A Série Estudos e Documentos publica trabalhos que busquem divulgar estudos econômicos, sociais, jurídicos e de gestão e planejamento em C&T, envolvendo aspectos tecnológicos e/ou científicos relacionados à área mínero-metalúrgica.

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SUMÁRIO

RESUMO

Nos últimos anos, os conceitos e objetivos do desenvolvimento sustentável vêm sendo extendidos, com sucesso, aos recursos minerais, e uma volumosa literatura vem sendo produzida sobre as inter-relações entre desenvolvimento sustentável, recursos minerais e necessidades sociais.

Entretanto, a inexistência de formalização, no sentido lógico da expressão, tem levado a algumas desinformações e desentendimentos desses conceitos e suas aplicações. É o objetivo deste trabalho salientar e indicar a necessidade de alguma formulação lógica para os conceitos de sustentabilidade e seus indicadores.

Palavras-chave: recursos minerais, desenvolvimento sustentável, indicadores de sustentabilidade

ABSTRACT

In recent years sustainability concepts and goals have been successfully extended to mineral resources and a body of literature on the linkages amongst the goals of sustainable development, mineral resources and societal needs has developed. However, a lack in formalization, in the logical sense, has led to some misunderstandings and misinterpretation of the concepts and their applicabilities. It is the purpose of this paper to stress and point out some necessary logical formulations for the sustainability concepts and indicators.

Key words: mineral resources, sustainable development, indicator of sustainability.

1 | INTRODUCTION

In a recent paper (Shields, Solar, Anciaux and Villas-Bôas, 2005) the authors stressed that a commitment to sustainable development needs integration of policies and development strategies so as to satisfy current and future human needs, improve the quality of life, and protect the environment upon which we depend for life support services. Since Brundtland´s proposal of the concept, societies the world over have embraced the principles and goals of sustainable development. They are debating and selecting sustainability goals, setting policies consistent with those goals, and enacting related legislation. Initially there were serious questions about the degree to which mineral resources fit in sustainability, given that they are not sustainable in the same way as are ecosystems or biological resources. However, people are coming to understand that mineral resources are an integral part of developed, modern societies and that a sustainable future is unachievable without the services they provide.

A thorough discussion regarding current issues on sustainable development, which impacts the minerals extraction industries was provided by myself on several occasions (Villas-Bôas, 1994, and Villas-Bôas & Beinhoff, 2002) and does not need to be herein repeated. However, for the sake of clarity of the concepts to be explained and indicated, I strongly recommend their readings.

It is my belief that some logical formalizations are needed regarding the concepts of Sustainable Development, Sustainable Development Indicators, Sustainable Ore body and Sustainable Mine, as referred to the minerals extraction industries.

If that is done, several misconceptions are prevented and all readers and involved parties would know what is been meant by such words. Thus, this proposed formal (logical-mathematical)framework for such themes and issues.

Also, it seems, the old Ricardo´s proposition on distinguishing between renewable and nonrenewable resources does not quite fit anymore, as such, in our actual, sustainable, development framework, for the sake of resource exploration and development, through its more recent paths and practices. Therefore, the suggestion of conceptualizing sustainable resources and non sustainable resources for that matter! These subjected to societal agreements, as proposed.

3 | SUSTAINABLE INDICATORS

Indicators and indices package complex mineral information into understandable forms for stakeholders, decision makers and public use (Villas Boas & Beinhoff, 2002). These mineral indicators must be useful as analytical, explanatory, communication, planning and performance assessment tools. Indicators help people understand the complexities associated with mineral resource management policy decisions, such as the interconnectedness of physical and environmental systems and the inevitability of making tradeoffs among conflicting management policy objectives (Shields & Šolar, 2005). Thus, the information contained in indicators can contribute to public understanding of the state of the world and the potential consequences of fulfilling various objectives, i.e., they can facilitate social learning (ISG, 2004).

4 | THE INDICATOR PROCESSES

Main features of the indicator processes of Latin America, the European Union and the United States are presented below (Shields, Solar, Anciaux, Villas-Bôas, 2005).

4.1 | Latin America

Background | In October 1999, CYTED (http://www.cyted.org), an official agreement between the Ministries of Science and Technology, or equivalent, in Iberoamerica, plus Portugal and Spain, launched via CYTED-XIII, one of its programs, a discussion on "Technological Challenges posed by Sustainable Development to the Mineral Extraction Industries", resulting in a publication under the auspices of CYTED, UNIDO, IMAAC and the Copper Study Group (Villas Boas & Fellows (eds.), 1999). Its aim was to prepare the mineral industries carrying on its operations in Iberoamerica to face the new challenges as well bringing government representatives into the new discussion.

Next year, 2000, enlarging the discussion, a "Mining Closure Experiences in Iberoamerica", document was presented and paved the road to present, in 2002, a publication titled Indicators of Sustainability for the Mineral Extraction Industry (Villas Boas & Beinhoff, 2002), which set forth some guidelines for starting the stakeholder process to conceptualize and build up such sustainable development indicators, taking into account:

- The particular branch of industry (metals, industrial minerals, energy minerals);
- The given physical environment in which the operations are conducted (rain forest, desert, temperate);
- The specificities of the country economy in which the operations are carried out;
- The existence, or not, of social pressure mechanisms in the particular region or country where the industry is located;
- The existence, or not, of R&D infrastructure in the region or

country where the industry is located to measure some of the measurable effects.

Goals | Indicators are supposed to ... indicate! However, what to measure and what, thus, to indicate? Formally, indicators are to be easily measurable and easily identifiable, when there is still time to act and propose solutions in a given set of risks/problems/performances. In reality, they measure the several, and eventually even contradictory, factors and events prevailing at a given predetermined time, in a given society or sub-sector of that society. Thus, creation of indicators brings together physical parameters, if identified and measurable, psychosocial parameters, whenever prevailing in the particular stakeholder group taking part in the creation process, inherently cultural parameters, "representative" of the region(s)/country(ies) where the action is taking place, etc. Indicators are a "mirror" of the anxieties of that set of stakeholders who established the indicator as a measure for the performance of industry and its commitments with sustainable development aims. They are dynamic in the sense of stochasticity, but can provide a minimum framework for decision-making and acceptance within a sufficient time.

Methods | Working Groups were established beginning in 1999 and continuing up to now, and are working under the aims and objectives of sustainable development on the following areas. The identified person and organization chair them:

- Land Use in Mining (Luis Martins, INETI/IGM, Lisbon) 2003.
- Geomechanical Risks. (Roberto Blanco, ISMM, Moa, Cuba) 2001.
- Fertilizers in Iberoamerica. (Hugo Nielson, UNSAM, Buenos Aires, Argentina) 2000.
- Industrial Minerals and Building Materials. (Benjamin Calvo, E. de Minas Madrid, Spain) 1999.
- Mining Heritage. (Arsenio Gonzalez Martinez, UHU, Huelva, Spain) 2003.
- Indicators of Sustainability. (Roberto C. Villas Bôas CETEM/

CYTED, Rio de Janeiro, Latin America and Jose Enrique Sanchez Rial, DEGEO, Cordoba, Spain) 2003.

These working groups hold regular meetings and reports of their discussions are available at http://w3.cetem.gov.br/cyted-xiii. They are in the process of disseminating the methodology of the stakeholder-based approach for developing the indicators, and discussing some groups of indicators. As usual, at the beginning of the process, circa 2000, the environmental indicators prevailed over the balance of others, but the set is evolving to balance "social indicators", "community indicators", Amerindians rights, etc. The method of the working groups is not to develop or propose common indicators, since Iberoamerica, as such, is just a cultural background area, legislated through several different legal diplomas. Rather they encourage discussions and propositions within the existing legal framework and diverse social setting of a given region.

The sustainable development indicators are grouped into the following categories, following the four pillars of sustainability (Villas Boas & Fellows (eds.), 1999):

- Mass Flow Analysis: minimization of mass generation is a must for mining sustainability;
- Environmental Impacts: minimization of heavy metals into environment and wastes; open pit against underground operations;
- Process Energy: the Free Energy challenge;
- Social Satisfaction: maximization of social indicators (health, ecology, jobs, rent, social security, local environment).

Scale | This is a fundamental question, which has to be addressed at the very beginning of the process to establish a set of sustainable development indicators, so that time, efforts, money and energy are put at the right place, at the right amount. Normally, medium to large extraction companies do develop or are in the process of developing LCA type of procedures, such that some of the most obvious environmental indicators might be at hand; the large ones do have a set of social in-

dicators at hand as well, which are quite helpful for some of their needs (company indicators). As a sector of an economy, as well, some indicators might be available, such as jobs, accidents, financing community events and festivals, total tonnage of extracted rock, federal, state and local tax payments, buying within a given municipality or region, etc. Sustainability, however, is an agreement that sets forward that your neighbor has to be as conscious as you are, otherwise there will be no major net gain. Thus, indicators have to focus on geopolitical areas. Realistically though, the process probably has to start from local or site scale and then expand.

Status | Since participation in the working groups are is voluntary, and they meet on average twice a year, and sometimes just once a year, their actions have been concentrated on disseminating propositions and results of discussions throughout their respective nets (industry, government and interested parties of their communities). It is envisaged that, by the end of 2005, some indicators might be available for reporting by several working groups.

Challenges and realities affecting the process

- Financial realities: Lack of financing is, obviously, a big deterrent to any collaborative process. When inadequate it might even invalidate the indicator development process.
- Geopolitical realities: In Iberoamerica, the geopolitical reality is a function of the geography of the region where the mineral development event is taking place: Andean, Amazonian, South Cone, Caribbean, Mezzo American. A given country could be made up of one, two or three regions, each having its particular interests and issues. Therefore, sustainable development indicators must be set forth for this geographical reality, vis-a-vis the overall policies of the country towards that particular geographic region.
- Difficulties in data collection: There is often considerable various in knowledge and skills within a given geopolitical/geo-

graphical region. Some regions or countries have limited scientific resources, and therefore fewer capabilities to propose, test, monitor and validate data and data quality. Errs in data aggregation are also prevalent in some areas.

4.2 | The European Union

Background | In May 2000 the European Commission published a Communication on "promoting sustainable development of the EU non-energy extractive industry" (European Commission, 2000). Its aim was to set broad policy lines for promoting sustainable development in the EU non-energy extractive industry. It identified a number of key challenges for the industry and set out a number of priority actions, which were considered necessary to maintain or improve competitiveness in this sector while achieving sustainable development. Stakeholder dialogue was one of the important issues mentioned in this Communication that should be improved to achieve a more sustainable minerals industry. Indicators are a useful tool to create a platform for dialogue where different stakeholders are able to define, discuss and evaluate the performance of industry and its contribution to society.

Goals | The indicators are to serve as a generally understandable means of communication between the different interest groups:

- the companies, which can represent their economic, ecological and social welfare benefits vis-à-vis other stakeholders.
- the national, regional and local administrations, which (depending on the legal conditions) examine these performances, and/or give access to land for mineral extraction.
- the public (local, regional or national population, NGO, media), whose interests are affected by existing or new sites.

Methods | A Working Group was set up in 2000 as a sub-group of the Raw Materials Supply Group. This Group met eleven times between its kick-off in December 2000 and January

2004, with extensive consultation occurring between meetings. The Working Group, chaired by the Enterprise and Industry Directorate General, consisted of about 20 experts from industry, Member States, a university and an NGO.

The first phase of the work involved agreement of the work programme and time frame. It was decided to develop the indicators taking a bottom-up approach and applying the characteristics used for the Global Reporting Initiative (GRI, 2000), i.e., that the indicators should have relevance, reliability, clarity, comparability , timeliness and verifiability. It was also agreed that the indicators should also adhere to SMART targets. The work was limited to those phases of the production process that involved the extraction of raw materials, primary refining and the use of secondary raw materials.

In order to develop relevant indicators, the working group relied particularly on existing initiatives, projects and studies, whose results could be adapted for the requirements of the extractive industry sectors. Therefore, an analysis of relevant projects and studies available at the time completed this first phase.

In *the second phase*, an extensive preliminary list of potential indicators was drawn up at the level of companies and sites. Considering the large number of SMEs in Europe, it appeared necessary to support those companies which do not have sufficient resources to develop sets of indicators independently, but have frequent contacts with other stakeholders. Nevertheless, very early in the process a distinction had to be made between indicators at company/site level and indicators at national (Member State) level. The preliminary list of indicators was divided in 4 categories: environmental, economic, social and institutional. They were presented using the following scheme: Key fields, Indicator, Measure and Ultimate goal.

In *the third phase*, the list of possible indicators was progressively refined. Reasons for deleting certain indicators included the level of complexity being too high; the unavailability of a good workable definition (e.g. biodiversity); (future) legislation

would already cover a certain aspect; or the limited relevance of certain indicators for the sector (e.g. CO^2 emissions). An initial list of 31 indicators was then subjected to a pilot test at the end of 2001, which involved 152 sites. As a result of this exercise, the list was shortened to provide 13 priority indicators at company level, and 7 indicators at Member State level. They were not developed with a specific policy application in mind, but instead were chosen because they provided a useful picture of the sustainability of the industry, while the data collection requirements were considered to be achievable.

Representatives of the Member States, however, identified that the data required to construct the Member State level indicators was problematic due to the lack of a legal base for this exercise. It was therefore decided to proceed with the data collection at company level and to consider other means of obtaining data at Member State level. However, progress has since been made, following discussions with Eurostat, in particular, on the contribution the industry makes to the Gross Domestic Product (measured as value added at factor cost), material demand per capita, and trade balance.

In *the fourth phase*, a questionnaire and guidance document explaining how to complete it was developed for the company level indicators. This was then circulated to individual companies via their trade associations in the second half of 2002. It is stressed that the exercise was voluntary, and companies were invited to participate. The responses from companies were sent to their associations, which collated the data received, before forwarding the aggregated data to the Commission. The Working Group prepared a draft report on the indicators which was endorsed by the Raw Materials Supply Group in January 2004 and shortly after published on the Commission's website. Unfortunately, because of the large number of companies supplying construction minerals, it was not possible to obtain a meaningful set of data for this sub-sector for 2001, so their results were not presented in the report. However, there

is a clear commitment from this sub-sector to participate more fully in future data collection exercises.

Following a Conference on Sustainable Development Indicators held on Milos, Greece, in 2003, an exchange of information and co-operation with other players such as the GRI, MMI (Canada) and the US SMR has taken place.

Scale | The aim was to develop indicators, which can serve at the following levels as a common basis for dialogue for all involved interest groups: companies and/or sites, industrial sectors, regional or national, and EU.

Status | The industry federations have started collecting data for the years 2002 and 2003. It is expected that a report on these data will be finalised in the first half of 2005. In parallel with this process, further consideration is being given to the questionnaire and guidance document in light of comments provided by the Working Group members.

The 2001 report was published on the Commission's website. Hardcopies have been produced and distributed by the federations (Euromines and IMA Europe). The report provides a useful baseline against which future years data can be compared.

Challenges and realities affecting the process

- Financial realities: Commission's involvement is mainly to costs involving chairing and hosting meetings of the Working Group, some translation costs and hard copy publications. Industry federations and companies have mainly contributed involving people to the process of the Working Group, investing time and money in the data collection process and disseminating the results.
- Difficulties in data collection: SME-dominated sector (see above), highly concentrated sectors (e.g. gypsum), business sensitivity of certain data (e.g. lime: energy efficiency) and motivating the companies in general to participate.

4.3 | The United States

Background - In its report "Sustainable America," the U.S. President's Council on Sustainable Development recommended that the Federal government develop national indicators of progress toward sustainable development in collaboration with the private sector and non-governmental organizations, and regularly report on these indicators to the public (PCSD, 1996). The United States Department of Agriculture Forest Service was an active participant in the Montreal Process and, along with other signatory nations, agreed to utilize the 7 criteria and 67 indicators of sustainability developed by the Montreal Working Group to report at regular intervals on the status of the nation's forests. The Forest Service subsequently committed to implementing the criteria and indicators (C & I) on the lands they hold in trust and to use them as part of their comprehensive monitoring program. Shortly thereafter, the agency created the Sustainable Forest Roundtable to provide stakeholder input and guidance to the implementation process. It was soon clear that the lack of indicators for rangelands, water resources and minerals in the Montreal C & I limited the agency's ability to practice sustainable resource management. Therefore, in 1999, the US Forest Service brought together representatives from 16 governmental and non-governmental organizations to discuss the development of a multi-stakeholder forum for creating C & I for non-renewable resources. Out of this meeting came the Sustainable Minerals Roundtable (SMR). The Sustainable Rangeland Roundtable was started the same year, and the Sustainable Water Resources Roundtable a few years later.

Goals | All of the U.S. resource Roundtables are self-governing processes that set their own agendas. The goal that the SMR set for itself was to develop a set of national scale C & I of sustainability for mineral resources. The indicators were to have broad applicability and be acceptable to a wide range of stakeholders, including agencies of the Federal government interested

in mining, minerals, and energy development, private firms engaged in non-renewable resource extraction and development, local governments, tribal organizations, and nongovernmental organizations. The primary purposes of the set of indicators developed by the Roundtable are as follows:

- to encourage a national dialog about how energy and mineral systems can best contribute to a sustainable America;
- to identify the types of information that will be needed for an informed public dialog;
- to highlight trends and priorities related to energy and mineral systems; and
- to support an interim assessment of the Nation's progress toward its sustainability goals in relation to non-renewable resources.

Methods | The SMR is co-chaired by the U.S. Forest Service and U.S. Geological Survey, and convened by Dr. Dirk van Zyl of the Mining Life-Cycle Center, MacKay School of Mines, University of Nevada at Reno. As noted above, participation in the SMR is open to all interested individuals. In order to facilitate broad participation, and involve diverse publics in the process, regional meetings have been held around the country since the fall of 1999. Over that time 153 participants from almost seventy federal agencies, mining firms, non-governmental organizations, professional organizations, academic groups and tribes have participated. Meetings were led by a professional facilitator and would begin with background presentations intended to familiarize newcomers with sustainability principles, indicator theory, scale concepts, and the work to date of the SMR. Thereafter participants would work collaboratively, or in subgroups, to define criteria and refine the indicator set. This process had both strengths and weaknesses. One strength was that participants felt a sense of ownership in both the process and the products of the Roundtable. Another was that the process was inclusive and welcomed input from a wide range of interested communities, which led to a more robust product. A potential weakness was the necessarily circular

nature of the process, given the need to review concepts and past work at the beginning of each meeting.

SMR participation has not been limited to attending the scheduled meetings. As specific areas of work have surfaced, work groups have formed to meet the demands of the task. In addition, in order to facilitate the gathering of data and the development of a group consensus, the Delphi process has been utilized by the SMR. In this "collaborative" process, the Delphi technique was used to provide a method of continuing the work begun at the meetings and allowing the group participants who were unable to attend a meeting to continue to contribute to the on-going work.

During the early stages of the SMR, participants decided that it was necessary to develop a sense of direction and set boundaries for the project. Over the course of several meetings, and through vigorous debate, a mission statement and a vision for the group were developed to serve these purposes. Additionally, it was determined that in order to maintain consistency and discipline over the selection and development of issues a set of guiding principles would also be necessary. Several meetings were devoted to identifying mineral sustainability issues and organizing frameworks. After reviewing the work of several other indicator processes, including the Canadian Mining and Mineral Indicator project, participants decided to utilize the Montreal Process criteria, with some modifications. Where the Montreal Process had developed seven criteria, the SMR scientists focused on a subset of four:

- Maintenance of Capacities to produce Commodities
- Maintenance of Environmental Quality
- Maintenance and Enhancement of Long-term Social, Economic, and Cultural Benefits to Meet the Needs of Societies
- Legal, Institutional and Economic Framework to Support Sustainable Development

Initially incorporated within the four criteria were approximate-

ly two hundred indicators. Over the course of discussion the numbers of indicators were first pared down to eighty-two and eventually to sixty-one (including the sub-indicators). For each indicator, six questions were answered: relevance to sustainability, scale to which they apply, whether the science exists, the amount of interest from stakeholders, whether the data exist, and the complexity, time, and resources necessary to populate the indicator. Based on the answers, indicators were allocated to either Phase.

Scale | Sustainability requires the analysis and interpretation of complex phenomena at multiple scales. However, inferring pattern and process at one scale based on information collected at another is fraught with potential difficulties. Some phenomena are applicable only at certain scales; others, such as production and safety, are relevant across many different scales. Although the SMR initially focused on national scale indicators, many of these indicators are based on the aggregation of site-specific data and so are relevant at smaller spatial scales as well. The Government Performance and Results Act requires, among other things, that agencies monitor the outcomes of their activities. In response the Forest Service has begun to apply sustainability indicators for forests, rangelands and minerals at the Management Unit scale.

Status | The SMR has completed selection of the initial set of 61 indicators. Progress reports on each criteria and associated indicators have been written and are being circulated. A meeting will be held in the summer of 2005 to solicit critical feedback from SMR participants, after which report will be created, reviewed, and published. Next steps include populating indicators with data, and extending to set to the fossil fuels sector. The SMR is also developing an integrated framework for the minerals indicators, as part of the work of the Integration and Synthesis Group (ISG). Comprised of leaders of the four roundtables and other projects, and under the sponsorship of

the White House Council on Environmental Quality, the ISG is developing a systems-based framework to be used to promote greater commonality in the C&I developed by the four roundtables. This will provide a mechanism for synthesis and the eventual reporting of national sustainability indicators for all lands and resources in the United States. The four resource indicator sets will also be used by the U.S. National Academy of Sciences' Key National Indicators Initiative.

Challenges and realities affecting the process

- Financial Realities: The Federal agencies that have sponsored the Roundtables to date are now facing significant budget cuts. Continued work populating indicators with data, and testing the validity of individual indicators, will depend upon the availability of funds.
- Difficulties in data collection: Indicators can be selected based on availability of data, or based on their contribution to understanding of sustainability issues, should data become available. The SMR took a mixed approach with the result that data do not currently exist for every proposed indicator. The SMR has no authority to requiring reporting of additional data by industry and no funding to undertake new monitoring initiatives. However, as the GPRA reporting process proceeds, it is assumed that some new data will become available at least on federal lands.

5 | SOME (NECESSARY) FORMALIZATION REGARDING SUSTAINABILITY AND SUSTAINABILITY INDICATORS FOR THE MINERALS EXTRACTION INDUSTRIES

A) Sustainable Development

A.1 let

$$R \equiv \bigcup_{0}^{n} R_i$$

where

$R \equiv$ is the set of all resources as, for instance
$R_1 \equiv$ natural resources
$R_2 \equiv$ environmental resources
$R_3 \equiv$ energy resources
$R_4 \equiv$ capital resources
$R_5 \equiv$ human resources
$R_n \equiv$ any resource

and

$R_o \equiv \phi$, i.e., no **resources at all**

A.2 let W be a transform such as

$$W : R \rightarrow D$$

where

$W \equiv$ is the transform work
$D \equiv$ is the set of development stages

and W a surjective function, i.e. it links at least one argument to every possible image.

A.3 let:

$$S_i \equiv \bigcup_{1}^{n} \{S_{i_1}, \cdots, S_{i_n}\}$$

be the set of development hypothesis where *n* is the number of subsidiary hypothesis which characterizes S_i respectively to *D*[1].

A.4 Now consider

$$S_d \equiv D \bigcup \{S_{d_1} \bigcap S_{d_2} \bigcap S_{d_3} \bigcap S_{d_4} \bigcap S_{d_5}\}$$

where

S_{d1} ≡ set of minimal use of natural resources

S_{d2} ≡ set of optimal (or maximal) use of physical flow resources

S_{d3} ≡ set of minimal use of energy resources

S_{d4} ≡ set of minimal use of environmental resources

S_{d5} ≡ set of maximal social satisfaction states[2]

such as

$$s \in \bigcap S_d \leftrightarrow (\forall S_{d_i} \in S_d, s \in S_{d_i})$$

and S_d is a no empty set

$$\mathbf{S_d} \neq \phi$$

A.5 thus

S_d = set of sustainable development scenarios belonging to *D* and having as constraints

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1 Observe that , $D \neq \bigcup_{1}^{n} S_i$ rather, S_i implies the acceptance of D !

2 Social satisfaction is the degree of societal acceptance of a given policy, or political agenda.

A.6 then

$$\bigcap_{1}^{5} \mathrm{S}_{\mathrm{d_i}}$$

represents the goals and targets of a political agreement[3], a political agenda, and setting for the agreed states of sustainable development[4].

B) Sustainable Development Indicators

B.1 Having defined, formally, sustainable development, in order to measure it one needs an indicator or indicators.

B.2 Let define effort (T) as a function, or transform, that attributes a positive number to every productive operation (P) or process.

B.3 thus

$$\mathrm{T} : \mathrm{P} \rightarrow \mathbb{R}^{+}$$

defined by

$$\mathrm{T(p)} = \Gamma$$

for every $\mathrm{p} \in \mathrm{P}$ and $r \in \mathbb{R}^{+}$ and $\mathbb{R}^{+}$ is the set of real numbers

B.4 Let define enhancement (E) as the benefit obtained by the person, or firm, *x* from *y* – also person, or firm – who performs or allows to perform the productive operation *p*

3 In this regard sustainable development might be regarded as a *Weltanschauung* (meaning a "*look onto the world*" in German) rather than a full Khunian paradigm shift, i.e., that describes a process and result of a change in basic assumptions within the ruling theory of Science.

4 Which, according Brundtland's report is the essence of *environmental sustainable development.*

B.5 Let:

$$\mathrm{E} : \mathrm{X} \cap \mathrm{Y} \cap \mathrm{P} \rightarrow \mathbb{R}^{+}$$

such as:

$$\mathrm{E}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) - \mathrm{E}\,(\mathrm{y}, \mathrm{x}, \mathrm{p}) - \mathrm{T}\,(\mathrm{p})$$

is the measure of agreement, (A), indicator of agreement, when the enhancement *E* (*x*, *y*, *p*) obtained by *x* from *y* through *p*, the disturbance *T(p)* which the operation *p* causes to *x*, and *E* (*y*, *x*, *p*) the enhancement obtained by *y* as retribution to *x* to performs or allows to perform operation *p*.

thus:

$$\mathrm{A}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) = \mathrm{E}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) - \mathrm{E}\,(\mathrm{y}, \mathrm{x}, \mathrm{p}) - \mathrm{T}\,(\mathrm{p})$$

B.6 if

$$\mathrm{A}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) = 0$$

it implies a mutual enhancement or benefit for *x* and *y*

$$\mathrm{A}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) < 0$$

$\mathrm{x} \in \mathrm{X}$, loses

$$\mathrm{A}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) > 0$$

$\mathrm{y} \in \mathrm{Y}$, loses.

B.7 for a community or nation or any social group, *G*, where $\mathrm{X} \subset \mathrm{G}$ and $\mathrm{Y} \subset \mathrm{G}$:

$$\mathrm{A}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) = \sum_{\mathrm{x} \in \mathrm{G}} \mathrm{E}\,(\mathrm{x}, \mathrm{y}, \mathrm{p}) - \sum_{\mathrm{y} \in \mathrm{G}} \mathrm{E}(\mathrm{y}, \mathrm{x}, \mathrm{p}) - \sum_{1}^{\mathrm{n}} \mathrm{T}\,(\mathrm{p})$$

where *n* is the number of productive operations considered involving *x* and *y*.

B.8 if

A (*x*, *y*, *p*) is a sustainable indicator, as

then

$$A_s = S_d \bigcup \{A_1, \cdots, A_n\}$$

where

A_i = is the set of agreements obtained under prevailing S_d conditions

C) Sustainable Ore Body

C.1 Let :

$$R_{s_i} = R \bigcup_{1}^{5} \{S_{d_1}, S_{d_2}, S_{d_3}, S_{d_4}, S_{d_5}\}$$

be the set of sustainable resources.

C.2 a sustainable are body (O_s) is such that

$$O_{s_i} = R_{s_i} \bigcup A_{s_i}$$

$$m \in \bigcap O_{S_i} \leftrightarrow (\forall A_{S_i} \in O_{S_i}, m \in A_{S_i})$$

where *m* is ore mineral reserve.

D) Sustainable Mine

D.1 applying the transform *W*:

$$W : Os \rightarrow M$$

where

M = Sustainable Mine Development

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