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Decision support frameworks and metrics for sustainable development of minerals and metals

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Abstract The Australian government-supported Co-operative Research Centre for Sustainable Resource Processing (CSRP) has undertaken a comprehensive review of sustainability metrics and decision support frameworks used by the global mining/minerals/metals sector. This paper provides a summary of that larger review. In particular, attention is given to the extent to which the plethora of current tools and approaches used by the industry are similar; the degree to which they conform with more formal approaches to decision making, as espoused by the management sciences community; and how indicators are, or should be, used to support decision making, or to set targets for achieving more sustainable outcomes from practices within the industry. We cite experience from six major companies within the sector as examples of current practice. Finally, we suggest how current best practice should be augmented by additional tools, which focus on information quality and management.

Keywords Decision support · Frameworks · Indicators · Sustainable development · Minerals

Introduction

In this paper, we take as our point of departure the view that minerals' development is not only justifiable in a future built around sustainability arguments, but is key to such. Minerals, and their metallic derivatives, are not "consumed" in a material economy—they are merely dissipated through a variety of uses. The challenge to delivering a sustainable future which is supported by minerals and metals is to ensure that the total social, environmental, and economic "footprint" of minerals' extraction, refining, use and disposal, is less than that of other material and technological interventions with which minerals and metals are competitive. This exercise goes hand-in-hand with decision making processes and practices within the industry. If one focuses on "decision making for sustainability", then what is needed is a set of tools and metrics, which can provide guidance and support to the minerals industry to achieve the following (Petrie et al. 2002):

- Position itself within a global economy, not solely as a provider of commodities, but as an integral link in delivering added value along the complete material transformation chain.
- Recognise its role in redressing the imbalances between "developed" and "developing" nations, wherein much primary minerals extraction and processing takes place.
- Choosing projects and technologies for minerals' development with due regard to all sustainability objectives.
- Optimising existing mining and minerals activities to deliver against sustainability objectives.

This is no small task, given the diversity of environments in which the minerals and metals sectors operate, and the scales of decision situations they encounter—from high level strategic planning-type situations, to tactical, design-type situations, through to operational practices. We argue that all of these

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decision situations are addressible with the aid of an appropriately structured decision support framework, which is populated with meaningful performance measures or metrics. In this paper, we review a number of frameworks which exist within the sector, and comment on their value. In particular, we challenge the structure and comprehensiveness of these frameworks with regard to their compatibility with accepted decision support frameworks used routinely by the Operational Research and Management Science communities to facilitate improved decision making within organisations and firms. We also look at the burgeoning sets of sustainability indicators which have gained currency since the advent of environmental and sustainability reporting within the minerals and metals industries, and comment on their suitability for decision making.

Sustainability decision support frameworks

The minerals sector faces real challenges in operationalising its intent to pursue more sustainable practices. This intent requires that it engage, in its core business practices, with a host of complex decision situations covering strategic, tactical and operational aspects of its business. Such decisions are those characterised by ill-defined problems, the need to consider multiple objectives and stakeholders, and varying degrees of uncertainty. A meaningful decision support framework (DSF) is one which can provide guidance on how to approach and resolve such problems, leading to decision outcomes which are proactive in promoting sustainability. The DSF is typically accompanied by an appropriate range of process, technology, economic and financial models pertinent to the decision situation at hand. From a sustainability perspective, these, in turn, need to be supported by environmental assessment models and some explicit consideration of relevant social issues. It is also important that the DSF be well aligned with the internal decision making processes of any organization or agency within the sector.

From a general standpoint, there is a significant body of literature in existence looks at structured approaches to decision making (by way of example, consider Belton and Stewart 2002; Stewart 1992; von Winterfeldt and Edwards 1986; and Keeney and Raiffa 1976). We argue that the generic decision cycle (Rosenhead and Mingers 2002) is ideally suited to decision making within the minerals and metals industries. The first stage of this systematic approach to decision making is called *problem structuring*—the aim of which is to identify the stakeholders, and obtain agreement about the exact decision at hand; the objectives that need to be satisfied by the decision outcome; the alternatives available, how to assess these (i.e. to what extent they meet decision objectives); and to elicit the preferences of stakeholders for particular decision outcomes. The next step in the decision making process (*problem analysis*) involves the evaluation of the alternatives under consideration, to determine to what extent these satisfy the decision objectives. This is followed by the selection of a preferred alternative, and sensitivity analyses to ensure that the conclusion is robust.

The decision making process described above is not linear. Iterations occur both between steps in the cycle, and the cycle as a whole, as more information become available or further clarity is obtained about the information that is required in each step. This structured approach to decision making can be applied in all decision contexts, and is the basis for an ideal DSF for the minerals sector. Of course, for different decision contexts, there are differences in the manner in which the two main stages of the cycle would be conducted and the tools required to support these.

Problem Structuring is essentially a discursive and deliberative process, and is best done through direct interaction between stakeholders. Rosenhead and Mingers (2002) provide a review of tools to assist in problem structuring. An important assumption of the decision analysis methodology is that those participating in the decision making process are willing to engage in discussion and to reach a consensus position on the problem structuring elements, in order to facilitate subsequent analysis of the problem—in other words that participants are interested in rational decision outcomes. In general, strategic and tactical problems tend to require more discussion and deliberation than operational ones, since the former often involve a variety of stakeholders with divergent interests; while, in the latter, the focus is more on the decision for a single entity, where there is a clearer basis for consensus. The outcome of a problem structuring exercise is often summarised by way of an objectives hierarchy, which shows the criteria that will used to evaluate the alternatives under consideration, and the attributes (expressed quantitatively or qualitatively) that will be enumerated to determine the relative performance of the alternatives. Several software packages have been developed to assist in drawing up objectives hierarchies. When used interactively, these provide an effective means of facilitating and recording the problem structuring discussions.

Problem Analysis: during problem analysis it is necessary to obtain data on the performance of the alternatives in all the criteria. This can be done by simply rating options relative to each other based on experience, or could involve more extensive data gathering and modelling to obtain more accurate performance information. A variety of methods and tools is available to provide environmental performance information. Important aspects include the choice of system boundary for modelling, and the quality of the performance indicators used. To avoid merely transferring environmental impacts to other stages of a production chain, or to other media, the importance of using more systemic models of industrial production systems is recognised. The philosophy of life cycle thinking (Wrisberg et al. 2002) can be applied to guide the scope of this analysis, and provide the spatial and temporal boundaries for modelling. A generic decision cycle is illustrated in Fig. 1. Note, this decision process is not linear, as iterations occur within and between all elements in the cycle included in Fig. 1.

The usual outcome of the problem structuring exercise is a hierarchy of objectives, which capture the main criteria, and which will be used for the assessment of the alternatives; and a set of attributes used to measure the performance of the alternatives against these criteria in the problem analysis phase. An example of an objectives hierarchy for decision making for sustainability is included in Fig. 2. This figure contains an additional level of detail for environmental considerations. In reality, objectives hierarchies can contain numerous levels, depending on the decision context, and the requirements of stakeholders. It must be recognized that this is a highly simplified objectives hierarchy, and more detailed ones will be required for particular decision situations (and will be informed, in large part, by stakeholder input).

There is explicit capacity within decision analysis to engage with the fact that the suite of performance indicators employed to capture the richness of the decision situation may well be incommensurate. A variety of approaches is available to handle this challenge (see Belton and Stewart 2002). For example, *Value function* methods rely on the translation of unit scores for individual criteria onto a value base which reflects decision maker preferences, and the weighted summation of value scores to achieve an overall value for each option under consideration. In this approach, weights are scaling constants, which capture inter-criterion preference information, and reflect the extent to which decision makers are willing to trade-off performance of options. As such, value function methods are inherently compensatory. Other methods, such as outranking approaches, attempt to build up a weight of evidence, through a series of pair wise comparisons, to suggest which options outperform others in individual performance criteria. Outranking methods, applied correctly, are close to non-compensatory in nature. No one decision analysis approach is preferred unilaterally. In practice, a variety of methods is often employed to gain richer insight into the decision situation.

Structuring decisions in this manner, and recording all elements of the decision making process, ensures that decisions taken are transparent and defensible. It is possible to develop an audit trail for the decision, and from this audit trail to record all the information

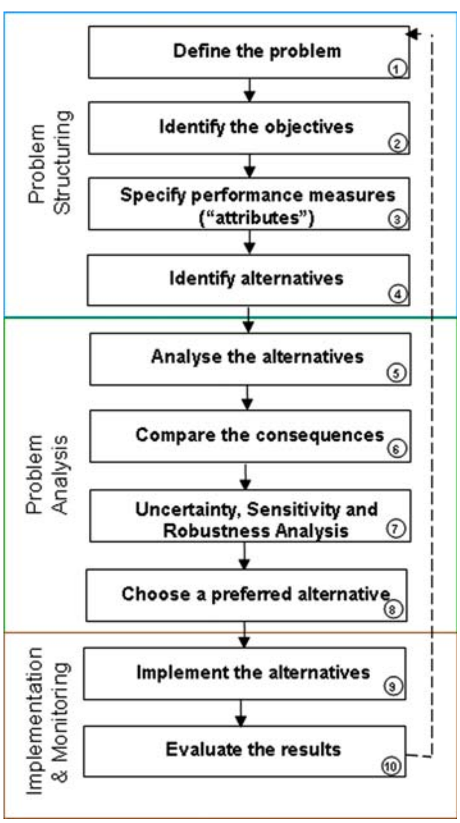

Fig. 1 Generic decision cycle

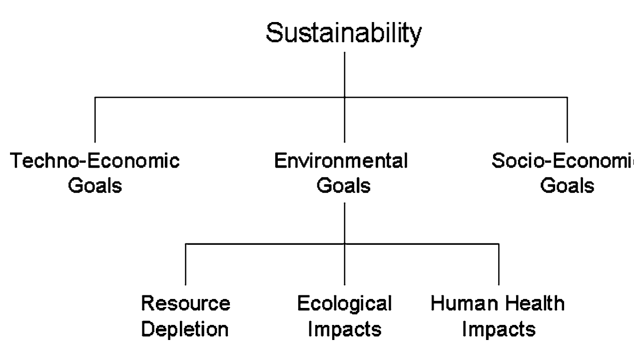

Fig. 2 Example of an objectives hierarchy

which was brought on board during the decision making process, and demonstrate how this information was used in reaching the final decision. The structure also facilitates and organises input from multi-stakeholder groups where necessary (with the understanding that direct stakeholder engagement is not necessarily possible in all decision contexts).

At this point, it is useful to summarise our observations. We can make the following assertions: based on the philosophy of life cycle thinking, and structured around the tools of decision analysis, it is possible to construct an approach to decision making which affords decision makers the opportunity to engage with all stakeholders in a decision, thereby improving the transparency of the process, and leading, hopefully, to better decisions with more robust outcomes. Any decision support framework should place emphasis on information gathering and management of uncertainty. Decision analysis allows for the incorporation of information from a variety of sources (i.e. based on many of the decision support tools already in existence and used routinely). Additionally, it suggests that it is the decision making process (and its underlying constructs) which are most important—not the methods of data collection themselves. That said, it is important to understand the underlying uncertainties in the information used to characterise a decision situation, without which our experience suggests it is often impossible to arrive at meaningful decision outcomes. In all decision situations, it is a case of ensuring that the requisite set of performance information is collected. This point is not to be understated. Too many researchers and practitioners in the field of environment and sustainability are bent on measurement and monitoring, when perhaps a focus on decision objectives would be more helpful in advancing the sustainability agenda.

In order to assist in the review of decision support frameworks used within the industry, it is helpful to challenge these in terms of decision analysis structures. Posed as a series of questions, Table 1 provides a comprehensive and convenient means by which to do this. In providing answers to these questions, it is possible to guide decision making practice along a more robust and defensible pathway. Our research considered more than 50 different frameworks in existence globally. The full set of frameworks reviewed, including their reference sources, can be obtained by contacting the Australian CRC for Sustainable Resource Processing (http://www.csrp.com.au). The frameworks review is available on CD, with a full set of operating instructions.

Using this table, we have attempted to define industry best practice (in terms of comprehensiveness of decision making protocols) from the list of frameworks examined, and to map these onto a conventional set of decision contexts (i.e. strategic, tactical and

Table 1 Frameworks analysis template

Problem structuring elements
Who is involved in the decision?
What are the objectives to be pursued?
Is this a screening, ranking or choice selection exercise?
What value chain elements are addressed?
What is the nature of the change (organizational policy, structure and management vs. company activities) and its relationship to biophysical and social environments
What is the severity of consequences envisaged from the decision? This will affect the required auditing process for the decision
Is this a single or multiple decision maker situation?
Is it a participatory or conflictual situation i.e. are rational approaches possible?
Are there other governance perspectives (are problem owners also the decision implementers)?
Is this a "snap-shot" time base, or prospective framing over an extended time period?
Is risk considered explicitly, and, if so, how?
How were alternatives generated?
Problem analysis elements
What are the indicators or metrics employed?
How appropriate are these in terms of stated decision objectives?
How is the issue of data quality assessed?
Is there a compensatory logic followed?
What is the valuation approach employed, and if weighting is used, then how?
Is there interest in arriving at a single index of performance?
What is the fit between outcomes and objectives?
How are uncertainty and robustness handled?
Is there any extrapolative benefit of the decision, from incremental benefit to system innovation?

operational). Our observations in this regard are shown in Table 2 below. We have suggested those frameworks which represent best practice with respect to both coverage and completeness for at least some of the considerations required for decision making. A number of the frameworks assessed demonstrate how objectives are linked to metrics through the definition of goals and indicators. It does, however, need to be stressed that it is necessary to revisit this definition of indicators during the problem analysis stage of any decision cycle, to ensure that metrics and indicators selected measure performance in the objectives as intended.

There are no frameworks which engage with all elements of the decision process. That said, the ICMM set of governing principles (ICMM 2003) provides a useful starting point for discussion. As a general rule, missing elements include:

- Verifying appropriateness of indicators in the context of decision objectives and goals: while this is referred to in ''Seven Questions to Sustainability: How to Assess the Contribution of Mining and Minerals Activities'' (MMSD 2002), no structured methodology for ensuring this match is presented.
- Complete data quality assessment: This is best addressed in ''Life Cycle Assessment of Nickel Products'' (Nickel Development Institute 2006), which is a function of the data quality elements required when conducting an ISO 14 040 Standard LCA (ISO 2004a, b). Of course, where non-LCA indicators are used, the value of this formal assessment approach remains untested.
- Elements which are explicitly absent from all frameworks are the identification of any compensation approaches or logic followed to explore trade-offs in performance scores; adequate identification and application of weights, which are specific to the decision context and/or suitable for the decision at hand; any indication of a comparison between decision outcomes and the initial objectives for the decision; and methodologies for the management of uncertainty and/or robustness assessments.

Ultimately what this review of frameworks has shown is that, while there are a number of frameworks which exhibit adequate, and even excellent, characteristics in one or more of the decision cycle elements, there is no single decision framework which is adequate on its own to support decision making for sustainable development in the minerals industry. The challenge facing the industry is to understand the contextual elements of the decision, which it is trying to take, and then to pick and choose the best elements from these frameworks for its specific decision context. This is not an elementary exercise. Beyond this, we advocate that the following elements need to be integrated explicitly into decision frameworks:

- The correct application of any compensation approaches when determining what trade-offs are acceptable between different objectives. Is a *balanced scorecard* approach preferred over a decision outcome which reflects excellent performance in some criteria compensating for poor performance in other criteria?
- Adequate identification and application of weights, which are specific to the decision context and/or suitable for the decision at hand. Weighting is a normative exercise, and needs to be conducted in a manner which allows stakeholders to declare value preferences for performance in any one decision criterion, independently of how she/he may feel about the other decision criteria.
- Methodologies for managing uncertainty and/or robustness assessments. This is the opportunity, within the overall decision cycle, to explore the significant risks and uncertainties present. The decision analysis approach to decision making allows consideration of empirical, valuation and future uncertainties in a manner which does not require that all risks and uncertainties be couched in financial terms. This is a powerful aspect of the approach, and allows greater value and perspective to be derived from the scenairo analyses and sensitivity studies which are employed to capture uncertainties.
- Comparing decision outcomes and the initial objectives for the decision. This is arguably the most important aspect of the decision process. It is here that the checks and balances of the exercise are assessed. An audit trail of the decision process is a valuable tool to facilitate this. The generation of an audit trail is reasonably straightforward if the decision analysis approach to decision making is adopted.

In summary, the emphasis in the decision support framework (DSF) should be on exploring the decision problem to gain greater insight into its full complexity, to promote mutual understanding amongst those involved in the decision process about their respective goals and preferences, and to ultimately enable the selection of a preferred course of action.

The value of the proposed DSF to minerals companies can be captured in the following:

Table 2 Allocation of best practice frameworks to different decision contexts

Decision element	Strategic	Tactical	Operational
Decision process	Seven questions to sustainability: how to assess the contribution of mining and minerals activities	Seven questions to sustainability: how to assess the contribution of mining and minerals activities	Seven questions to sustainability: how to assess the contribution of mining and minerals activities
Decision framing	ICMM principles	ICMM principles	ICMM principles
Stakeholder identification and engagement	The global dialogue of governments on mining/minerals and sustainable development	Public participation guidelines for stakeholders in the mining industry	Public participation guidelines for stakeholders in the mining industry
Stakeholder capacity building		Using ILO standards to promote environmentally sustainable development	Using ILO standards to promote environmentally sustainable development
Including entire value chain	Green lead	Green lead	
Addressing recycling of metals	Non-ferrous metals and their contribution to sustainable development (NFMSD)	Non-ferrous metals and their contribution to sustainable development (NFMSD)	
Frameworks for specific decisions	National: NRCAN sustainable development strategy	Investing: finding capital for sustainable livelihood businesses: a finance guide for business managers Technology development: aluminium industry technology roadmap Planning for closure: strategic framework for mine closure	MCA operational framework (this is not a definite assertion as the guidelines are still in draft form)
Transparency	Extractive industries transparency initiative (EITI)	Extractive industries transparency initiative (EITI)	Extractive industries transparency initiative (EITI)
Accountability	AccountAbility 1000®	AccountAbility 1000®	AccountAbility 1000®
Temporal and spatial scales	Seven questions to sustainability: how to assess the contribution of mining and minerals activities	Seven questions to sustainability: how to assess the contribution of mining and minerals activities	Seven questions to sustainability: how to assess the contribution of mining and minerals activities
Extension of the risk framework	WRI framework for mining	WRI framework for mining	
Generation of alternatives		Public participation guidelines for stakeholders in the mining industry	Public participation guidelines for stakeholders in the mining industry
Inclusion of all decision analysis elements	Life cycle assessment (LCA)	Life cycle assessment (LCA)	Life cycle assessment (LCA)

Table 2 continued

Decision element	Strategic	Tactical	Operational
Indicators	Financial and governance: the Dow Jones sustainability index Environmental: national strategy for ESD Environmental regional areas of protection: state of environment reporting (SOE) Environmental global areas of protection: the UNEP SETAC life cycle initiative Social: headline indicators (but limited) Integrated indicators: headline indicators	Financial and governance: the Dow Jones sustainability index Environmental: national strategy for ESD Environmental regional areas of protection: state of environment reporting (SOE) Environmental global areas of protection: the UNEP SETAC life cycle initiative Social: headline indicators (but limited) Integrated indicators: headline indicators	Environmental: national strategy for ESD Environmental global areas of protection: the UNEP SETAC life cycle initiative
Appropriateness of indicators in terms of objectives	Seven questions to sustainability: how to assess the contribution of mining and minerals activities	Seven questions to sustainability: how to assess the contribution of mining and minerals activities	Seven questions to sustainability: how to assess the contribution of mining and minerals activities
Consideration of uncertainty	Life cycle assessment of nickel products	Life cycle assessment of nickel products	Life cycle assessment of nickel products

1. The DSF can be thought of as a management protocol for the requisite information to support both the framing and analysis of the decision situation. This results in an audit trail being developed of all the intermediate steps in the decision, how these arose and were resolved, who had input, what assumptions were made, and what risks and uncertainties were considered. This aids both the transparency and defensibility of the decision outcome, and highlights the accountability of key players in the decision. Rigorous application of the DSF should enable its integration with existing decision making processes used by minerals companies.
2. The DSF enables explicit consideration of risk and uncertainty, by reducing the number of decision parameters to a few meaningful ones which capture decision objectives/criteria, and consider empirical, valuation, and future uncertainties. Application of the DSF allows for consideration of both qualitative and quantitative metrics, without the requirement that everything be reduced to a pseudo-financial cost. In this way, all risks can be explored systematically. The roles (and benefits) of scenario analysis and sensitivity studies for assessing both valuation-type and future uncertainties within the DSF are clearly identified.
3. The DSF can help identify which variables play a major role in the decision outcome, and can assist in the development of simple graphical tools to support the decision makers in their analysis of these key variables. In particular, the DSF should demonstrate compatibility with existing decision making practices, whilst highlighting the additional value it brings.
4. Information availability is key to the value of the DSF. Where such information is not available from existing sources, the DSF can point the way to the scope and detail of predictive models which are required. This goes beyond models of processing technologies, and includes models of the value chains wherein these technologies are applied, and which are representative of the relevant physical, infrastructural and environmental subsystems. There is a need to explore how these models inform the values and perspectives of those involved in the decision making process, and to integrate this knowledge within the decision support framework at an appropriate level of information detail and complexity. Businesses recognise the financial, technical/plant and skills/capacity dimensions of sustainability as well, and models of these may be required also. In many

cases, these models have a generic value in their own right, and can be used in subsequent decision analysis situations.
5. Because of the explicit ‘‘problem faming’’ component of the DSF, there is a real opportunity to generate options for consideration (be these of a strategic, tactical or operational nature) which are less reductionist and ‘‘closed-form’’ than might otherwise have been proposed. As such, there is greater propensity to both capture stakeholder concerns in the process, and demonstrate that these are met by the selected decision outcome(s).
6. The DSF is capable of being applied across a wide range of decision situations. Hence, experience gained in any particular decision problem is cumulative, and will assist companies in building a database of ‘‘best practice’’ in decision making. Equally importantly, experience gained in the application of the DSF will shorten decision making lead times, and tangibly reduce the cost of decision making by ensuring that the requisite information is available at the right time to support decision making.
7. The DSF can highlight what explicit value there is in the set of sustainability indices used for company reporting, and direct attention to where the value of these might be meaningfully enhanced. This is explored further in the next section of this paper.

Only once a comprehensive framework is available will it be really possible to decide what indicators or performance metrics are suitable for the decision at hand. In the next section, we focus specifically on the use of sustainability indicators by the minerals sector, and challenge their usefulness for decision making.

Sustainability indicators

Within the context of sustainability, an indicator is defined as a *measure of the performance of an entity with respect to a specific externality*, where the *entity* may be a single unit operation, a manufacturing plant, an operating company or a corporate entity, and the *externality* may be the environment, the community or the profitability of the company. The term *key performance indicator* is sometimes used to identify indicators which represent the most significant performance measures. Such a measure of importance is subjective and will vary depending on how the indicators are to be used. Hence, the distinction between ‘‘key’’ and other performance indicators is not made further here.

The indicators chosen as performance measures can be either a direct determination of the quantity of interest (natural indicators), or a measure of another performance indicator which is directly related to the item of interest (proxy indicators). Proxy indicators are often used when the performance in the category of interest is not easily measurable. Three broad categories of indicators or performance measures are commonly identified in the context of sustainability, these being *environmental*, *social*, and *technical*. Other variations of these groupings have also been proposed in literature, including the inclusion of *economic* performance with technical performance and *political/governance* indicators with social indicators. The isolation of separate economic and governance categories can also be made.

Uses of indicators: sustainability reporting and decision making

Sustainability indicators are generally used towards two broad objectives, being *sustainability reporting* and, less commonly (though not less deservedly), *decision making for sustainability*. *Sustainability reporting* generally relies on indicators which are easily measurable. These indicators fall into two broad categories; namely *progress* indicators, which measure progress towards sustainability; and *transgression* indicators, which measure symptoms of environmental degradation or social disenchantment. *Sustainability reporting* indicators generally include a combination of measurable and predicted future performance measures. Both these sets of indicators are essentially transgression indicators. *Decision making* indicators, however, require that the performance information be available at the time of the decision making process. Given that most decision making situations are prospective, then these indicators are therefore generally *predicted* measures of performance, with the prediction being based on models of the system, and information gathered from past experience. Not all *sustainability reporting* indicators can be used for *decision making*.

A number of guidelines are found in open literature for aiding the selection of sustainability reporting indicators. These are discussed below. Guidelines for the selection of indicators for decision making are, however, less common. The main reason for this observation is that each decision may require a significantly different set of information to support the decision process, and an infinite number of indicators is potentially available to decision makers. Hence proposing a definitive set of guideline indicators for all decision making is difficult, and, we would argue, largely futile. A second reason for this observation is that the use of decision analysis (Belton and Stewart 2002) for sustainability is still a relatively young "science". It is suggested that, over time, broad, indicative guidelines for the selection of indicators to support sustainable decision making given a specific decision context will be developed.

Analysis of the status quo with respect to development and use of indicators

Existing generic indicator sets

Generic indicator sets have been proposed by various organisations with interests in sustainability. These indicator sets are, in general, focussed on company reporting towards sustainability. Five such sets of suggested indicators have been identified. These are:

- the sustainability indicators proposed by the World Business Council for Sustainable Development (WBCSD 2006);
- the report on company environmental reporting published by UNEP (1994);
- the reporting standards suggested by the Global Reporting Initiative (GRI) (2002);
- the sustainable development progress metrics recommended for use in the process industries, as developed by the UK Institution of Chemical Engineers (2003); and
- various sets of metrics produced by academic researchers (eg. Azapagic 2004).

All five works suggest a similar range of indicators for reporting. These are broadly divided into the categories presented above (environmental, social and techno-economic). Two further categories of indicators are also discussed here, namely governance and integrated indicators. The following is a broad summary of what the indicator sets cover:

- Environmental indicators are concerned with the impact of an entity on the environment. Environmental indicators will include aspects of resource consumption (e.g. fossil energy, water etc.); emissions (e.g., CO_2, SO_2 flows); "volume-equivalent" indicators (e.g. CO_2 equivalents for global climate change, where CH_4 represents 23 CO_2 equivalents); land use impact indicators (e.g. soil organic matter (see Mila i Canals et al. 2006) or pollution plume dispersion (see e.g. Hansen et al. 2002); and proxy indicators as discussed previously (e.g. where the number of people exposed to an emission is used to represent the health impact of that emission).
- Techno–economic indicators refer to the economic/financial performance of an entity, its impact on the economies in which it operates, and relevant technological indicators. Indicators of economic performance have long been reported to great detail in financial reports, but the sustainability aspects (i.e. the impact on economies) are generally not captured. Economic indicators include capital costs, operating costs, profits, investments, assets, taxes, community development (e.g. investments in health and welfare), etc. These are generally natural indicators and are often normalized against production figures. Technology indicators capture information relating to technology modifications, advances and limitations, and will include measures of safety and operability.
- Social indicators refer to the impact of an entity on society, which includes employees, customers and the community. Reporting on social performance is often infrequent and inconsistent across organisations (Global Reporting Initiative 2002). Social indicators can include aspects of employment (job creation, wages, training and education); welfare (public health, shelter, education, safety, etc.); human rights issues (empowerment, equity, redress etc.); and the impact of products and services on consumption behaviour. The majority of social indicators employed in a given decision situation are likely to be proxies for the actual desired indicator.
- Governance indicators include general strategic business issues such as ethical considerations, public acceptability and corporate image. This may include reporting on aspects such as the development, implementation and auditing of management plans, goals and targets, etc.
- Integrated indicators are still currently in early stages of development, but have potential to become generally applicable or organisation specific.

S*ystemic* indicators link performance at the micro level (organisational) with economic, environmental or social conditions at the macro level (regional, national or global), and include ratios of actual to sustainable emissions/discharges based on limits set by governments etc, such as effects of production emissions/discharges on biodiversity. *Cross cutting* indicators bridge information across two or more sustainability elements, and include a composite measure of diversity (economic–social–environmental), eco-efficiency (economic–environmental) and externalised costs of emissions (economic–social or economic–environmental). These are not considered further here.

Reporting in accordance with the GRI

A significant number of companies within the minerals sector are reporting, or are working towards reporting, according to the GRI framework. We have reviewed the reporting performance of six major minerals companies, listed here only as "Company X". The following general observations are highlighted:

- Most of the companies perform well in core indicator categories which are informed by their existing policies and procedures. These are indicators generally located within the "social" grouping of the GRI indicators. The integrity and comprehensiveness of such policies was not, however, surveyed as part of this current work.
- Most of the economic indicators suggested by GRI are comprehensively reported by all companies, although the level to which information in these indicators is aggregated differs between companies. Good economic reporting is expected—the reporting indicators required by the GRI parallels those which are traditionally contained in corporate financial reporting.
- The most significant variability in reporting between, and within, companies is in the "environmental" indicators, both in terms of the number of indicators for which information is provided, and the degree of aggregation of data. Information presented ranges from site level, to commodity level to country/region to group level, with little consistency both within and between companies. We highlight the fact that these inconsistencies make comparisons between companies difficult.

The GRI and decision making towards sustainability

Although the GRI represents a reporting framework, there is merit in analysing whether the information contained in GRI reports has value in terms of self-learning and decision making. It is acknowledged that information may be used in different ways by different external stakeholders (such as investors, regulators and NGOs) to make decisions about the organisation. At this point, our anlaysis concentrates on internal decision making within an organisation.

In summary, the following observations are possible:

- The majority of economic indicators are seen as useful for decision making. These indicators typically represent the factors reported and used in financial assessments of organisations. Decision making on the basis of economic indicators alone, however, does not imply "good" decision making towards meeting the goal of sustainability.
- Many of the social indicators relate to the GRI requirement that certain policies/procedures be in place. The existence of a policy or procedure does not, however, necessarily mean that the information contained in such a policy/procedure, or gathered in support thereof, will be able to support decision making in any way, and, in particular, those which have a bearing on sustainable development.
- Only some of the environmental indicators reported may be useful in the assessment of new projects, although traditionally these have been used solely to identify where a project may transgress environmental regulations.

Despite the commitment by most of the major mineral resource companies to GRI-level reporting, we could find no evidence of how reported numbers are actually used in decision making. By way of example, Company A suggests that they: "...contribute to sustainable development by helping to satisfy global and community needs and aspirations, whether economic, social or environmental. This means making sustainable development considerations an integral part of our business plans and decision making processes". Company C makes a similar claim to: "...support sustainable development, by incorporating social responsibility, economic success, and environmental excellence into our decision making process". Company D identifies that: "...achieving sustainable development requires decision making that integrates economic, environmental, social and governance goals. Such decision making includes... decisions where economic, environmental and social goals are all advanced, trade-off decisions ... and ...no-go decisions that are non-negotiable, such as breaches of human rights. The way resources companies integrate their economic, environmental and social business decision making also contributes to sustainable development." Despite the commitment to these principles, no indication is given of the methodologies followed in decision making, nor how the indicators presented are used to support these aims.

Aggregation and decision making

Aggregation refers to the grouping or summation of data for various *business units* such as site, operating company, commodity or group/corporate level, and/or *temporally*, as weekly, monthly or annual data. The degree of aggregation of indicators which is appropriate for decision making is a function of the level at which the decision is being made. Three nominal levels of decision making are identified:

- Decisions of a strategic nature will include strategic planning and decisions regarding capital investments and acquisitions. Examples of strategic planning decisions include the development of company policy, long term business planning (e.g. to meet forecasted material requirements), strategies for resource management and strategies for the development of new technologies. For such decisions, aggregation of indicators to the corporate or operating company level, averaged or predicted over a number of years, may be appropriate.
- Tactical decisions may include decisions for the design and development of new facilities or technologies. These would in general require site and region specific indicators.
- Operational decisions relate to the management of facilities and include changes to the operation of the facility or minor design changes that do not require review of operating permits or licences. Operational decisions generally rely on collecting data on existing situations or evaluation of past experience, usually on a site level.

Significant variability in aggregation approach is seen both within and between companies. Performance reports within a company range from detailed information at the site level to group level aggregation, depending on the parameter being reported and the organisation. For example, for direct energy use by primary source (indicator EN3):

- Company A reports breakdown percentages of total energy obtained from different primary sources
- Company B presents total energy for the group but does not distinguish between direct and indirect energy
- Company C reports total direct energy for the group
- Company D presents a breakdown of the amount of energy used on individual sites, and
- Company E identifies total energy for the group and each commodity, and consumption per tonne of selected products.

It is not possible to determine how accessible the information used to compile these aggregated indicators is to decision makers. In addition, it is unclear over what time scales figures used to compile these aggregated indicators are reported—daily, weekly, monthly?—and whether these are consistent across indicators. Depending on the decision context, consistency in the time scales to which indicators are reported may be important. Transparency on how indicators are aggregated will help to ensure that indicators used are suitable for comparison.

Normalisation

Normalisation is carried out in order to place performance metrics in context relative to a reference value for easier comparison between performance scores. Examples of reference values include production volumes, average yearly environmental load and the number of inhabitants in a country or continent, average performance of the sector, average performance of the company in the last x years, international best practice, etc. Normalization thus reveals the magnitude of effects in relative terms. It does not, however, say anything about the relative importance of these effects—though it may assist in helping decision makers arrive at an indication of relative importance across all indicators. In company annual reports, normalisation is carried out against production volume or mass. None of the companies investigated here employed any other reference value.

Benchmarking

Benchmarking refers to placing the performance of an activity in context by relating it to previous performance of that business unit; of other similar organisation/industry/sector averages; or best practice, and using that to guide performance improvements. None of the company reports studied here benchmark performance with anything other than company internal data. This internal data represents either performance for the previous year, or from a reference year from which progress towards a goal is being tracked. This information tracks only incremental progress towards sustainability goals. That said such information is useful in highlighting trends in movement towards pre-defined goals/targets, which may themselves be the result of formulating decision objectives. As an example, Company F suggests that by ''... reporting normalised energy consumption figures, individual business units can set targets and benchmark against similar companies''. No indication is readily available of how or whether this is done. The only exception is that this company reports its progress towards meeting the requirements of the Mining Charter in South Africa, where the industry committed to achieving a target of 40% of management positions being occupied by historically disadvantaged South Africans within 5 years of the implementation of new minerals legislation.

Target setting and measuring progress

A review was conducted to determine at what levels companies set targets for improvement, and how progress towards these targets is measured and reported in annual reports. Few generic statements can be made about the outcomes of this review. Targets for different indicators are set at different levels, ranging from the group level, to the commodity level, to the site/operating company level. In addition, some targets are influenced by the rules and regulations of individual countries in which companies operate. Some targets are long term, whilst some are set only for the year ahead. In many cases it is unclear whether annual targets are an attempt to move towards achieving an overall long-term target.

Conclusions

This paper has attempted to do three things:

- To review decision support frameworks and tools which are in place within the minerals and metals industry.
- To examine the use of sustainability metrics within the sector, both for reporting and decision support.
- To overlay on this collected knowledge base some consideration of more formal decision making theory and practice, and to suggest how Decision Analysis can be overlaid on existing practices to provide a meta framework for decision support.

What is immediately apparent is that there is a vast body of literature on sustainability metrics, and, to a lesser extent, decision support frameworks, already in existence within the minerals and metals sector. That said, much of what exists is devoid of context, and there has been little synthesis carried out. When one looks outside the sector, too, the picture is not too dissimilar. Our analysis has shown that, even for those companies which are reputed leaders in the sustainability debate within their own sectors, there is little in the public domain, which demonstrates how sustainability metrics and frameworks are actually used to support decision making, and whether better decision outcomes are achieved as a result.

Looking specifically at decision support frameworks within the minerals and metals sector, it is clear that there is potential to create a hybrid decision support framework built on best practice modules from a range of sources, including MMSD and ICMM. However, when these processes and tools are critiqued against the more formal, and fundamentally robust, tools of decision analysis, they are found to be deficient in several key aspects of decision making practice. In particular, processes for problem structuring, including stakeholder engagement and elicitation of preferences, appear to be missing or inconsistently applied. Beyond this, the whole process of Valuation, in which preference information is used to inform decision trade-offs, is missing from most minerals-sector frameworks. We have provided a "meta-framework" which builds on best practice within the industry, augmented by decision analysis tools where needed. The value of this approach remains untested, however, and it will be necessary to identify meaningful demonstration studies through which to test this approach. The Centre for Sustainable Resource Processing (CSRP) has identified this as a key research question, and will be pursuing this further over the next 2 years.

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