SUSTAINABILITY ASSESSMENT OF BAUXITE RESIDUE MANAGEMENT: THEORY, METHODOLOGY AND APPLICATION

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Abstract

Decisions on bauxite residue management are surrounded by high degrees of uncertainty and absence of agreed indicators and metrics. The alumina industry therefore supported the development of a *Quantitative Methodology for Strategic Assessment of the Sustainability of Bauxite Residue Management* which combines strategic outlook with quantitative outcomes-based assessment. The methodology compares current practice with ideal values, derived from sustainability aspirations. An indicator system combines *management* indicators (for planning, management and reporting systems); *condition* indicators (state of environment and communities surrounding residue operations), and *operational* indicators (technical and economic performance). They have three hierarchical levels: *Headline Performance Indicators* (six, measuring sustainability objectives); *Key Performance Indicators* (twenty four, measuring sustainability impacts) and *Performance Measures* (flexible set, measuring operational contributions). Performance is measured on a five-level ordinal scale.

A Sustainability Assessment Tool was developed, and was piloted at an operating residue storage facility. Its unique advantages are the universal performance measuring system for environmental, social and economic outcomes, and the strategic orientation towards improvement and innovation in residue technology. It complements existing audit protocols and strategic planning processes, and demonstrates that even with imperfect knowledge and uncertainty, quantified sustainability tools can be developed that aid in decision making on development and implementation of residue strategies and technologies.

1. Introduction

The Alumina Technology Road Map listed high-level strategic goals for the alumina industry to address its technology needs over the next 20 years. One of these goals related to dealing with Bauxite Residue: "*Developing methods to achieve a 1,000 year ecologically sustainable storage of red mud and other solid wastes in existing storages, and make substantial progress in storage for later reuse as well as achieve substantial progress in the reuse of red mud" (AMIRA International 2001).*

The alumina industry therefore commissioned the project reported here to develop and apply a quantitative methodology to evaluate current and proposed bauxite residue storage practices in a sustainability framework. The resulting *Quantitative Methodology for Strategic Assessment of the Sustainability of Bauxite Residue Management* achieves its design specifications in regard to strategic outlook, sustainability assessment and quantitative evaluation (Van Berkel *et al.* 2007). The research was carried out as AMIRA Project P772 by the Centre for Sustainable Resource Processing and the Parker Centre for Hydrometallurgy on behalf of the industry sponsors: Alcoa, Aughinish Alumina, BHP Billiton, Rio Tinto Aluminium and Hydro Aluminium. This paper summarises the key findings of that project.

2. Sustainability Context

Sustainability has become an important driver for change in the minerals and metals industries. Over the past 10-15 years there has been much debate in industry, government, academia and society at large about the role of mining and minerals in sustainable development (MMSD 2002). The full ramifications of the global quest for sustainable development are however by no means clear yet, but the industry has at the highest levels already made profound commitments to sustainability, for example through the sustainability charter of the International Council on Mining and Metals (ICMM 2003), and the local- and commodity-specific operational frameworks and action plans that have been developed in response (IAI 2003; MCA 2004a; b; IISI 2006).

Primary aluminium production remains pivotal from intra-generational equity considerations, which are embedded in the sustainable development agenda (IAI 2003; 2004; van Berkel 2007). Primary production, including mining, refining and smelting each have a distinct environmental footprint, including land use change, energy use and greenhouse gas emissions and waste generation (Norgate *et al.* 2006). This project provides a solution to the problem of sustainability assessment of bauxite residue storage, one of the key elements in the environmental footprint of aluminium.

3. Assessment Methodology

A variety of assessment frameworks and sustainability indicators has been proposed at strategic, tactical and operational levels (GRI 2002; Azapagic 2004; GRI 2005; Petrie *et al.* 2005; GRI 2006), but their applicability for strategic planning and pro-active management of specific sustainability issues of the minerals industries, such as bauxite residue management, has been questioned by industry operators. The assessment methodology for bauxite residue management was therefore constructed around the following key design criteria (Van Berkel *et al.* 2007):

1. *strategic outlook*: the methodology must support a strategic assessment of the organisation's effort to define a long term sustainability vision for its residue operations and track its achievements towards the realisation thereof;
2. *sustainability assessment*: environmental, social, technical and economic outcomes of bauxite residue management must be considered in an integrated manner, during and beyond the operational life of residue storage facilities, on a sustainability timescale, notionally some 1,000 yrs; and,

3. *quantitative evaluation*: the methodology must facilitate tracking of progress towards sustainable bauxite residue management over time and between sites.

3.1 Strategic Planning

Strategic planning starts with defining the outcomes the organisation sets itself to achieve. In the context of sustainability assessment for bauxite residue this is split into two components, one external and one internal to the organisation. The external component determines an ideal state for bauxite residue storage. This is defined by a set of Ideal Values for all sustainability indicators. These Ideal Values are input to the internal visioning processes, leading to the definition of the *best reasonable sta*te defined by Best Reasonable Values for all sustainability indicators. The ideal state is determined from sustainability aspirations by an approach known as '*back-casting'* (Holmberg 1998). It defines what is highly desirable from sustainability perspectives and only constrained by fundamental limits in physical, chemical and/or social sciences (for example laws of thermodynamics). This ideal state is generic and independent from situational, technical or operational circumstances of bauxite residue management at any particular operation. The best reasonable state reflects best imaginable performance, preferably approaching the ideal state, with current and conceivable future technology and engineering. It can be understood as the stretch-target for improvement of residue management, unconstrained by current technology, economics and operational practices. Even though it is defined internally by the team in charge of the sustainability assessment, the best reasonable state is expected to be site-independent. It is therefore best viewed as a corporate-level or sector-level stretch-target rather then a site-specific stretch-target.

The strategic planning and sustainability back-casting approaches were integrated in the assessment process, as illustrated in Figure 1.

The key steps involved are:

1. *Ideal Values (IVs):* the IVs have been set in the assessment system, based on sustainability ideals that are deduced from various sustainability frameworks, and within the fundamental limitations inherent in the natural and social sciences and engineering (e.g. the laws of thermodynamics).
2. *Best Reasonable Values (BRVs):* a BRV is determined for each sustainability indicator by the organisation that undertakes the sustainability assessment. It is the outcome of visioning and consensus building, and reflects the organisation's common understanding of what would or would not be possible with imaginable technology, management effort and determination.
3. *Current Practice*: is established by performing the sustainability assessment on the existing bauxite residue management system to identify improvement opportunities through gap analysis in relation to the BRVs.
4. *Planned Future:* the Planned Future is defined by a set of target values for each sustainability indicator as the basis of an improvement plan.
5. *Actual Performance:* as the organisation implements its continuous improvement plans, it is expected that Actual Performance will improve and over time approach the levels reflected in the Planned Future, and that progress will be continually assessed in relation to the improvement plan.
6. *Strategic Alignment:* continual re-alignment of the Planned Future should be made in light of progress achieved and improvements in technology, understanding and commitment to close the gap to the best reasonable state over time.

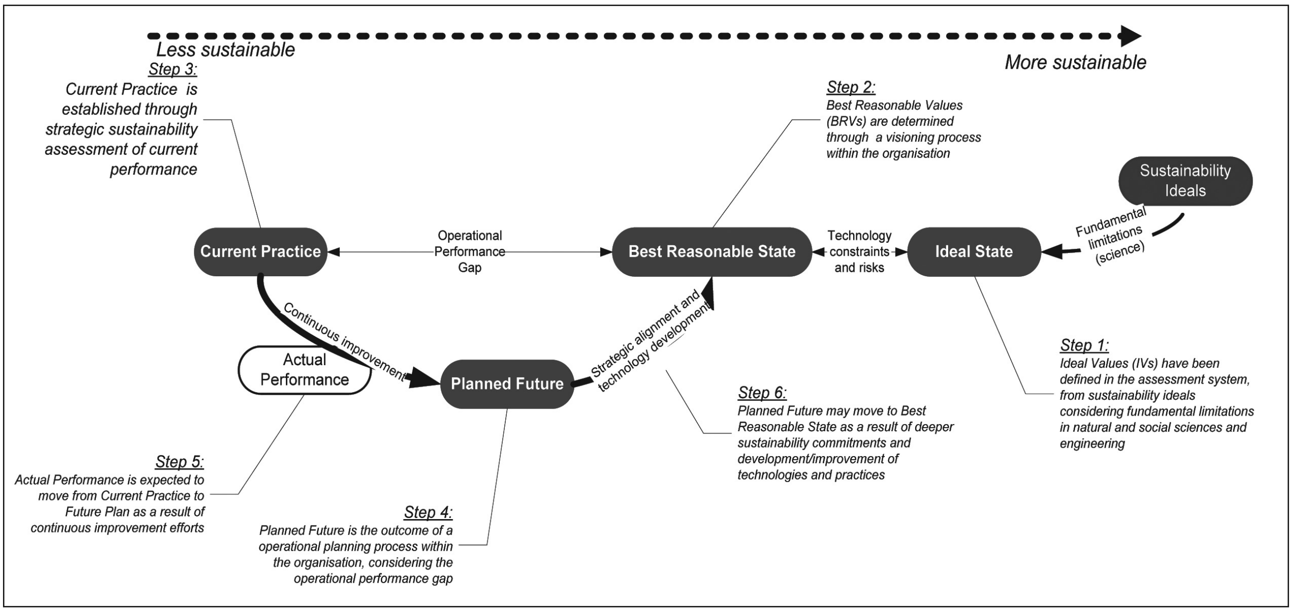

Figure 1. Strategic outlook in the sustainability assessment methodology (source: (Van Berkel *et al.* 2007)).

There are thus two mechanisms at work to improve the sustainability of bauxite residue management. Firstly, at the *operational* level, Actual Performance is expected to improve over time from Current Practice to Planned Future as a result of continuous improvement processes. Secondly, at the *strategic* level, it is expected that with a deepening of commitment to sustainability and improvement of technologies, the organisation will redefine its own goals for the Planned Future.

3.2 Sustainability Assessment

Previous research (Petrie *et al.* 2005) has identified *"Seven Questions to Sustainability: assessing how a mining project/ operation contributes to sustainable development"* (the *"7Qs framework"*) (IISD 2002) as the leading methodology for sustainability assessment in the minerals industry. The 7Qs framework was therefore used as the basis for the specific methodology development for bauxite residue management. Its key strengths are its ability to cater in a comprehensive and fairer manner for project positives and negatives in all three sustainable development pillars, its alignment with key minerals industry sustainability charters, its roots in real practice and its proven applicability in diverse situations. The 7Qs framework was utilised to deduce a register of sustainability issues for bauxite residue management. The seven questions were (with extensive industry input) applied to a generic alumina project (comprising an alumina refinery, bauxite residue storage facility and associated materials handling, infrastructure and utility systems) in order to construct a list of sustainability issues applicable to an alumina project. This list was subsequently reviewed to select those sustainability issues that are significantly influenced by bauxite residue management. This resulted in a list of fourteen sustainability issues for bauxite residue management, which were grouped into five overall performance areas, respectively: governance, society, environment, economy and technology.

Next the structure of the environmental performance measurement standard ISO 14031 (ISO 2000) was applied to these 14 sustainability issues. This resulted in a list of 55 performance elements for sustainability assessment of bauxite residue management. These elements were then extensively reviewed and integrated into the final consolidated set of 24 principal sustainability indicators. These sustainability indicators fall into three categories on the basis of the nature or type of the performance evaluation (Van Berkel *et al.* 2007). *Management Indicators* rate the existence, comprehensiveness and resourcing of the planning, management and reporting systems and practices in place for residue operations. *Condition Indicators* describe the condition of the environment and communities that have in the past been, are currently and/or could in the future be impacted by the residue operations. *Operational Indicators* quantify the operational performance of the bauxite residue management system.

The indicators are organised into the following hierarchical levels (Van Berkel *et al.* 2007):

- *Headline Performance Indicators (HPIs)*: indicators at this highest aggregation level measure performance against sustainability *objectives*, for example maintaining community well-being and environmental integrity. The HPIs are therefore universally applicable regardless of the storage system in use and location parameters for the residue storage operation (environment, settlements, community, etc.).
- *Key Performance Indicators (KPIs)*: measure sustainability *impacts*, for example the severity of leaching into groundwater and of potential or actual impacts on human health and safety. The types of sustainability impacts measured by the KPIs are generic and so KPIs are universally applicable to all bauxite residue operations. However location specific considerations (environment, community, settlements etc.) may make some KPIs more relevant and important than others. This is catered for by the inclusion of weighting factors.
- *Performance Measures (PMs)*: measure *operational contributions* to sustainability impacts, and are site-specific. For example residual caustic, alumina and water content in bauxite residue are all PMs that contribute to 'resource use efficiency' as the KPI.

Figure 2 illustrates the indicator system for the strategic assessment of the sustainability of bauxite residue management. For clarity only some example PMs for KPI 2.3 have been included. Similar sets of contributing PMs have been established for all other KPIs.

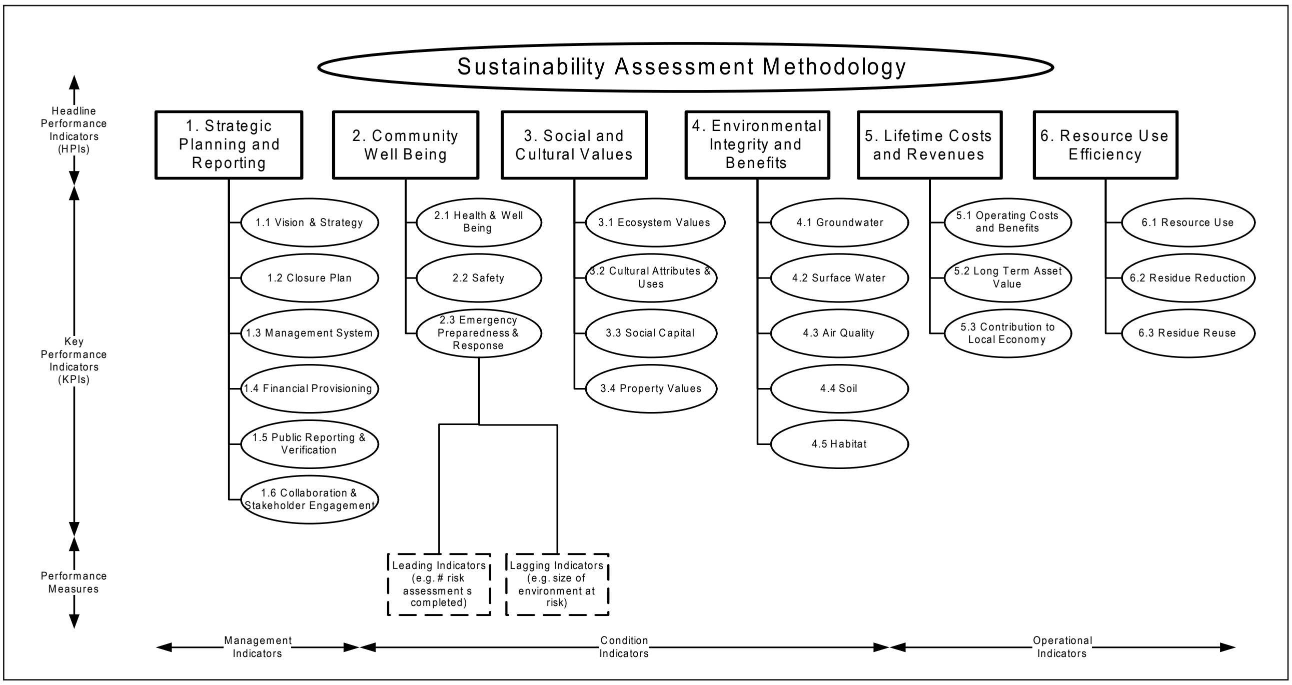

Figure 2. Overview of the indicator system for the sustainability assessment of bauxite residue management (Source: (Van Berkel *et al.* 2007)).

3.3 Quantitative Evaluation

Performance is primarily assessed at KPI level, and then integrated to HPI level. A five level semi-quantitative ranking system has been developed (Van Berkel *et al.* 2007). The performance levels are referred to as Level 1 (lowest) to Level 5 (highest). Throughout the evaluation system, the notional baseline (i.e. no significant impact) is Level 3. For performance levels 1 and 2 there is respectively a major and minor degradation due to the residue operations and for performance Levels 4 and 5 respectively a minor and major improvement due to the residue operations. Note that these numbers only provide a *ranking*, but NOT a *scale of values* (Level 2 is not twice as good as Level 1). The performance at HPI level is calculated as the average (weighted according to user-defined weighting factors) of the performance level at the constituent KPIs.

The evaluation scheme is illustrated in Figure 3, for a management indicator (KPI 1.4), a condition indicator (KPI 4.3) and an operational indicator (KPI 5.2). The starting point is whether or not the prerequisite for assessment on the respective KPI has been met. If not, the documentation and/or justification for a detailed evaluation on the respective KPI is not available, and hence the KPI is rated as not assessable. When the prerequisite is met, the evaluation can proceed to compare the performance of the respective operation with the five performance level specifications. The ranking system is thus based on level specifications which are unique to each KPI. As an illustration Table 1 contains the level specifications for these indicators.

emerging and possible technologies and practices. Optional weighting factors can be defined for individual KPIs. The weighting allows for consideration of location-specific conditions, for example on water indicators to differentiate between residue operations in arid or tropical climates.

2. *Base Case Assessment*: perform the assessment for each KPI. The base case assessment involves three main steps: preparation for assessment, assessment of current practice and determination of planned future. The supporting evidence for the assessment is also recorded to maintain transparency of the assessment result.

Table 1. Example level specifications for management, condition and operational indicator (respectively KPI 1.4, KPI 4.3 and KPI 5.2) (summarised from: (Van Berkel *et al.* 2007)).

	KPI 1.4: Financial Provisioning	KPI 4.3: Air Quality	KPI 5.2: Long Term Asset Value
Prerequisite	A *financial reserve* has been set aside to finance closure, rehabilitation and ongoing management	An *up-to-date inventory of potential air pollutants* and appraisal of potential impacts on air quality	*Long term worth* of post closure established under different scenarios
Level Specifications			
1 (lowest)	*Financial provision* has been established specifically for closure, rehabilitation and ongoing post-closure management	Air shed containing and surrounding residue operations *unhealthy for people* or will *not sustain ecosystems*	Benefit/Cost (B/C) ratio for closure, rehabilitation and ongoing post-closure management = 0
2	Necessary actions for closure, rehabilitation and ongoing post-closure management of residue storage facilities *have been costed*	Air shed could cause *nuisance for people*, can sustain *ecosystems with reduced biodiversity, productivity and/or resilience*	0<B/C<0.25
3 (neutral)	Financial provision caters for *different operational scenarios and engineering and natural risks*	Air shed does *no harm or nuisance to people* and can *sustain the ecosystems existent prior to residue operations*	0.25<B/C<0.75
4	*External auditing* of costs and of the sufficiency of the financial provision	Air shed *healthy for people* and could *enhance its associated ecosystems*	0.75<B/C<1.25
5 (ideal)	*Periodic review of the appropriateness* of the financial provision in light of both closure, rehabilitation and ongoing management efforts required and risk and liabilities	Quality of local air sheds improves so that ecosystems that depend on it *recover to levels of diversity and productivity considered pristine in local context*	B/C>*1.25*

The assessment methodology has been further developed into a Sustainability Assessment Tool (SAT) for bauxite residue operations. The tool provides the sustainability indicators and their performance level specifications to assess the sustainability performance of any particular residue operation and identify gaps that can be addressed with improvement efforts. A PC-based interface has been developed using standard office software. The software tool guides the assessment team through the assessment process, provides links to explanatory information on each sustainability indicator, tracks outcomes of the assessment and their justification, and can store supporting technical, management and/or other documentation.

4. Application

By virtue of its strategic focus, the application of the sustainability assessment methodology is intended to support the identification, evaluation and implementation of improvements in all applicable sustainability aspects of bauxite residue management. The assessment is carried out according to the following three-stage process (Van Berkel *et al.* 2007):

1. *System Set Up*: customise the assessment system to the residue operation being assessed. This starts with confirmation of the Best Reasonable Values. These will result from company internal visioning and consensus building processes, during which the team in charge of the strategic sustainability assessment will confirm what is considered '*best reasonable*'. In doing so, they will consider the Ideal Values, which are pre-defined in the assessment system, and will apply their collective knowledge of existing,

3. *Continuous Improvement:* development and implementation of specific improvement plans to achieve the planned future state (as determined in the base case assessment) for all KPIs. It is expected that this stage will be incorporated in routine project implementation at the particular residue operation.

The results of the base case assessment can be graphically displayed in various ways. Two basic presentations for the base case assessment result are given in Figures 4 and 5 (Van Berkel *et al.* 2007). Figure 4 shows a notional assessment result within one HPI group (in this case HPI 4: Environmental Integrity and Benefits). Each set of bars shows respectively the performance levels in current practice, planned future, best reasonable state and ideal state (from left to right). The first five sets of bars present the evaluation by individual KPIs (KPI 4.1-4.5) and the two sets on the right hand side show the integrated result for the HPI (i.e. averaged over the five contributing KPIs), with and without weighting of the KPIs. Figure 5 shows a notional assessment result covering all HPI groups. The six HPIs are on the axes of the spider web. Once again the performance levels are included for current practice, planned future, best reasonable bauxite residue and ideal bauxite residue, but in this case they are presented as lines resulting in four hexagonal shapes within the spider web. The area enclosed by each shape provides an indication of the overall performance.

The SAT was piloted at a residue operation of one of the sponsoring companies. It was found that the company in collaboration with other stakeholders is actively planning for the closure of the residue operation. The overall vision for closure, rehabilitation and ongoing management is therefore relatively well developed and appropriate financial provisions are made (HPI 1 group). The condition indicators (HPI 2, 3 and 4 Groups) show that regulatory compliance is being achieved and that social and environmental impacts are being minimised beyond compliance requirements. The SAT helped to identify future challenges related to the ultimate restoration of social and environmental values to pre-operation status. The SAT also helped identify some opportunities to improve the processes for tracking impacts and benefits, including financial benefits (actual and potential) of residue (HPI 5 Group). Residue reuse is an area in which considerable research is being devoted, but the objectives of high volume, low cost useful applications are yet to be achieved (HPI 6 Group).

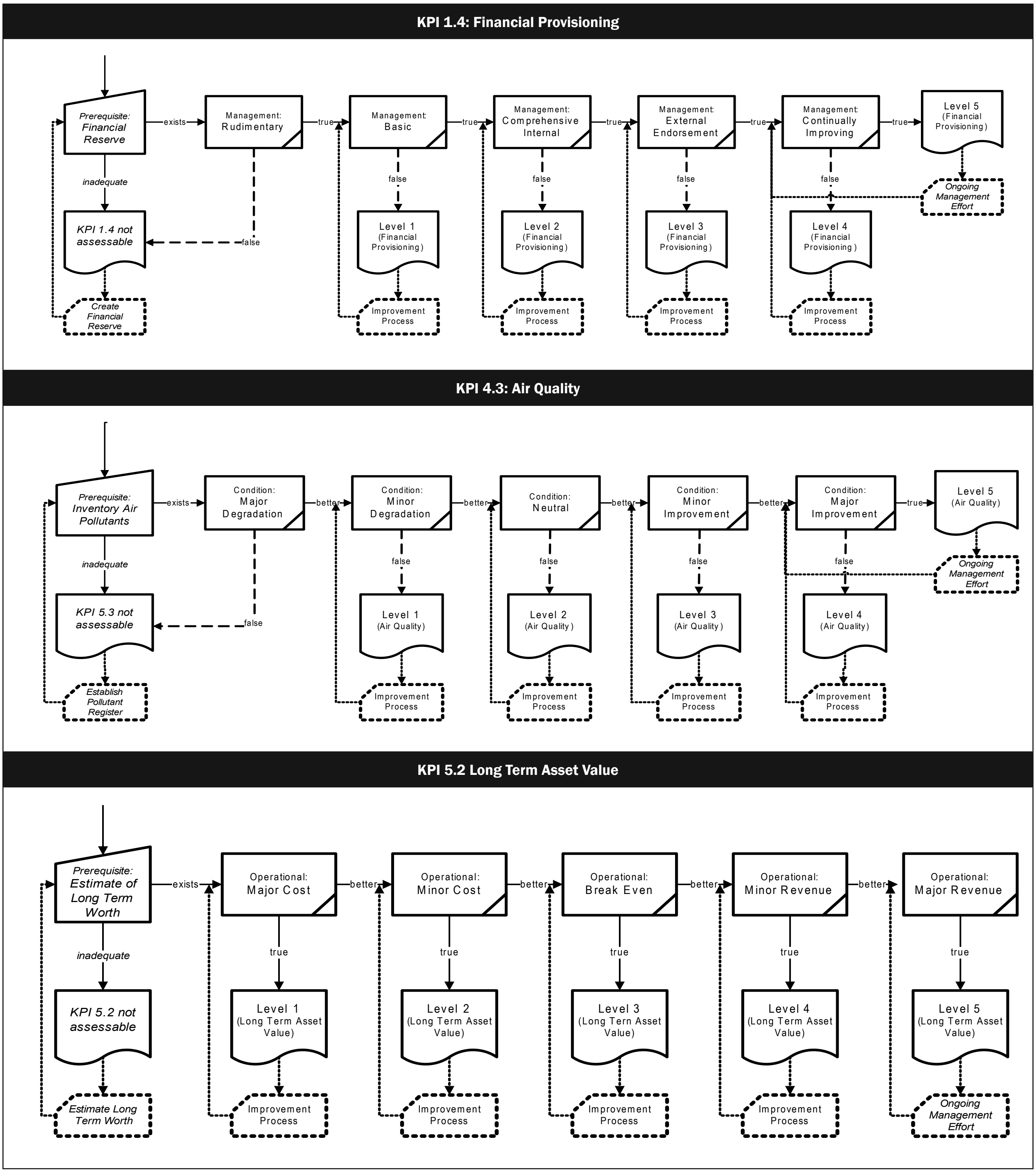

Figure 3. Illustration of the assessment scheme for management, condition and operational indicators (respectively KPI 1.4, KPI 4.3 and KPI 5.2) (source: (Van Berkel *et al.* 2007)).

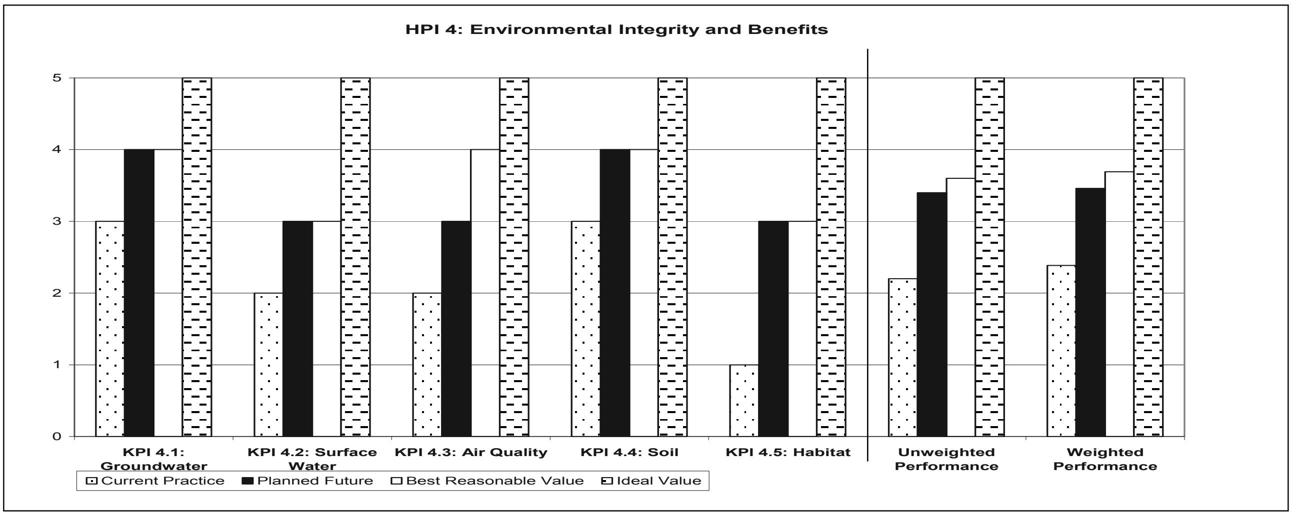

Figure 4. Illustration of an example assessment result within one HPI group.

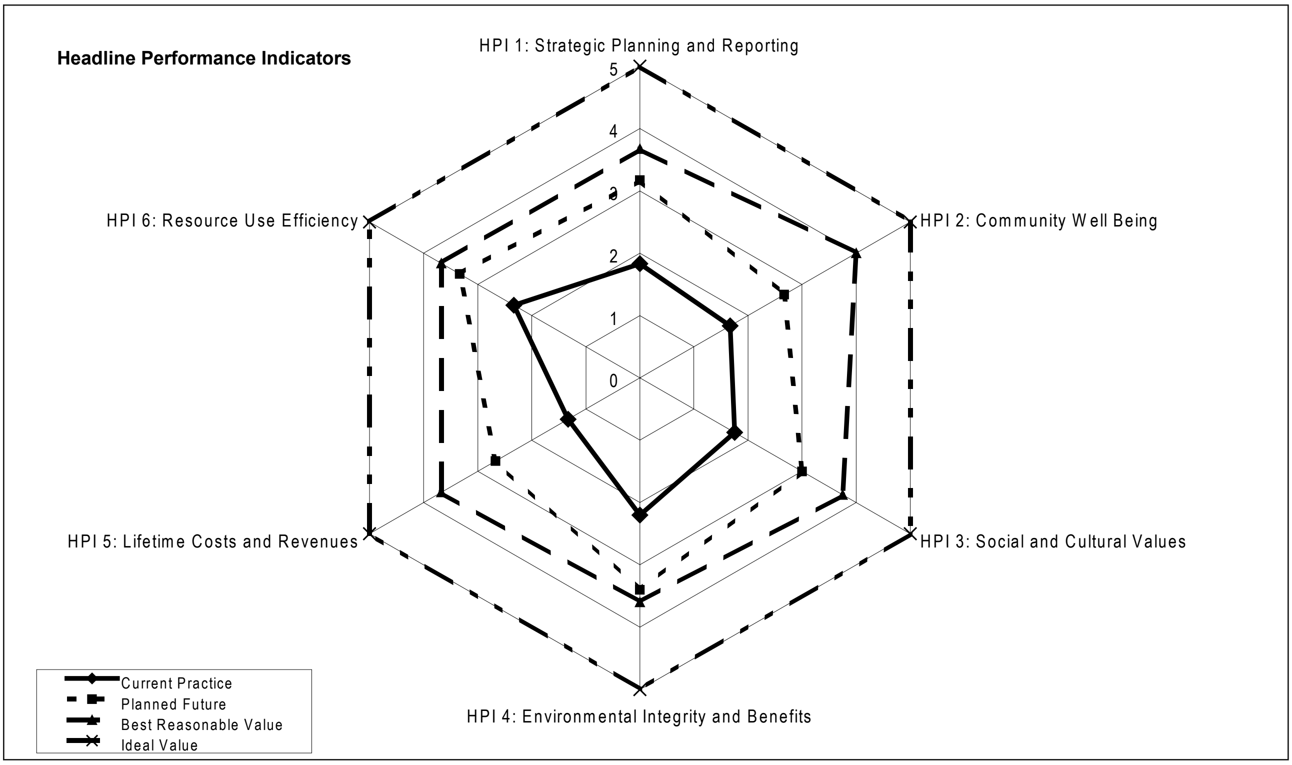

Figure 5. Illustration of an example overall assessment result including all HPI groups.

The overall feed back from the evaluation team and the company management was that the SAT provides a valuable and practical addition to the company's suite of evaluation, audit and planning processes for bauxite residue management. The SAT is consistent with existing business processes, and as such could be incorporated without any major difficulty. It was noted that the SAT added a different perspective, both in its incorporation and integration of the three legs of sustainability (social, environment and economic) into one uniform semi-quantitative evaluation, and through its forward looking, strategic design. This strategic aspect differentiates the SAT from traditional audit processes and provides a bridge to strategic business planning processes.

5. Concluding Remarks

This project demonstrated that it is possible to synthesise leading practice sustainability thinking into a strategic and practical assessment tool for bauxite residue management. In particular it was found that (Van Berkel *et al.* 2007):

- High level sustainability aspirations are a meaningful starting point for strategic planning and management of a sustainability issue;
- The "back casting" methodology for sustainable development is highly compatible with strategic business planning;
- The focus on the long term sustainability of a residue operation provides a basis for consideration of both positive and negative contributions from the operation to sustainable development at the local and regional level;
- A combination of different types of indicators (management, condition and operational) is needed for an integrated assessment of past, current and future sustainability performance of an operation;
- Structuring the sustainability assessment with hierarchical groups of sustainability indicators achieves a practical balance between evaluation on high level sustainability aims (as reflected in Headline Performance Indicators) and thoughtful consideration of operational and other details

that determine sustainability performance (with the Key Performance Indicators and Performance Measures);

- Performance evaluation with an ordinal system of performance levels is a practical way to achieve a degree of quantification in strategic sustainability assessment that is helpful to drive continuous improvement and innovation.

The SAT is a leading example of sustainability assessment which could be expanded to include the alumina refinery, bauxite mine, aluminium smelter and production, consumption and recycling of aluminium products, and could also be applied to other minerals and metals operations.

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