Sustainable Life Cycle Management: Indicators to assess the sustainability of engineering projects and technologies

Alan C. Brent and Carin Labuschagne
Chair: Life Cycle Engineering, Department of Engineering and Technology Management
University of Pretoria, Pretoria, 0002, South Africa
Tel: +27 12 420 3929; Fax: +27 12 362 5307
alan.brent@up.ac.za; carin.labuschagne@up.ac.za

1. Introduction

Business, as one of the three pillars of society (the other two being government and civil society)[1], has a responsibility towards the whole of society to actively engage in the sustainability arena[2]. The pressure is therefore mounting for businesses to align operational processes with the three objectives of sustainable development[3]. Four different types of drivers for the incorporation of sustainability into business practices have been identified[4]. An adaptation of the identified drivers is illustrated in Figure 1.

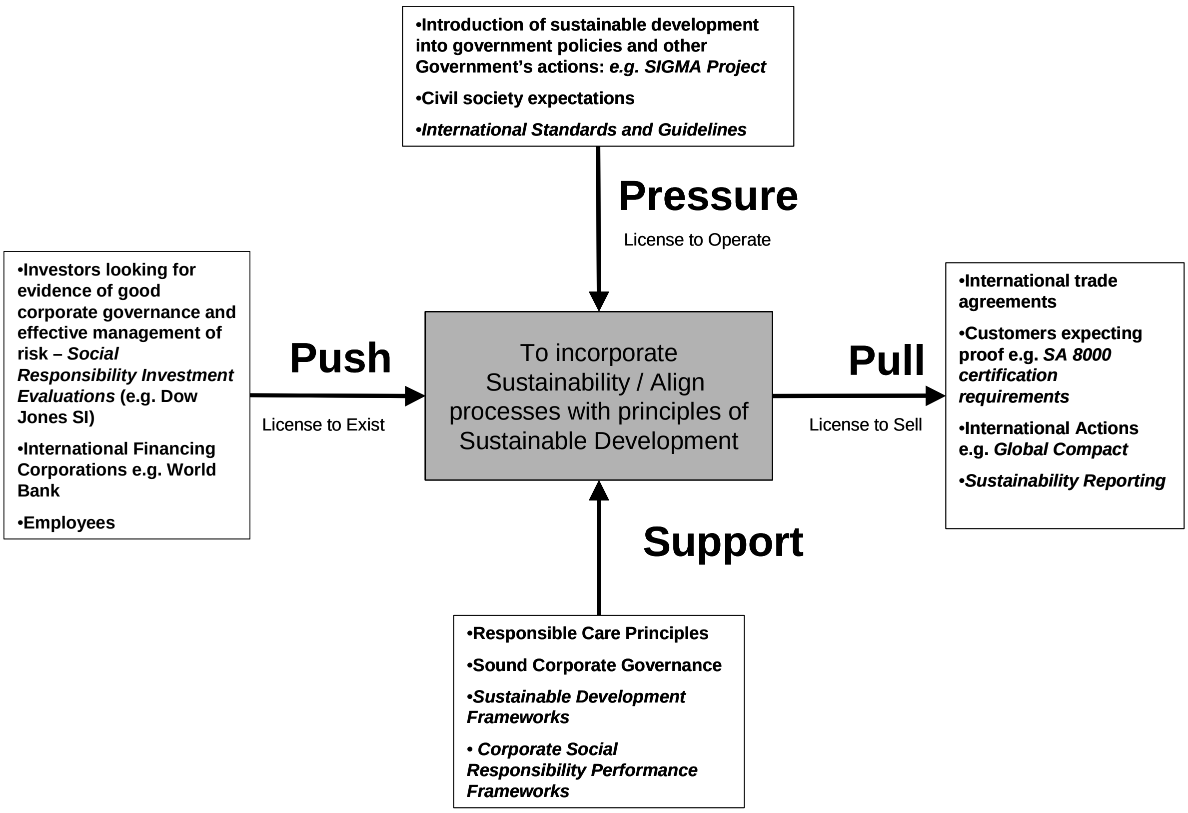

Figure 1: Drivers to incorporate sustainability into business practices

[1] Wartick, S.L. and Wood, D.J., 1998. International business and society. Blackwell, Malden, United States of America.
[2] Holliday, C.O., Schmidheiny, S. and Watts, P., 2002. Walking the talk: The business case for sustainable development. Greenleaf Publishing, Sheffield, United Kingdom.
[3] Keeble, J.J., Topiol, S. and Berkeley, S., 2003. Using indicators to measure sustainability performance at a corporate and project level. Journal of Business Ethics 44: 149-158.
[4] Goede, F., 2003. The Future of SH&E in the process industry with the focus on products. Sasol Group Presentation, Department of Engineering and Technology Management, University of Pretoria, South Africa.

The International Institute for Sustainable Development (IISD) has subsequently suggested that businesses can gain a competitive edge, increase their market share, and boost shareholder value by adopting and implementing sustainable practices. This can be done by companies "*adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future*"[5].

A sustainable company in industry thus does not exclude business development and profit, but rather guides itself along a route of environmental protection and social responsibility[6]. However, stakeholders are now demanding proof of the "sustainability" of companies by progressively demanding reports on the overall sustainability performances of operational initiatives such as undertaken projects or technological innovations. The aim of this paper is to propose methodologies to assess the sustainability of such operational initiatives in industry, i.e. to assess to what extend the operational initiatives are aligned with the principles of sustainable development. In order to do so, three questions must be answered:

- Which aspects of a technology or project must be assessed internally? The interaction of different life cycles from an industry perspective must be addressed.
- What must be considered and measured through such an assessment? A framework of sustainable development criteria, relevant for operational initiatives in industry, must be defined.
- How must these criteria be measured? Two types of sustainable development indicators or assessment procedures are introduced and discussed, specifically for the environmental and social dimensions of sustainability.

2. The interaction of different life cycles from an industry perspective

A prerequisite for aligning operational initiatives, such as undertaken projects or technological innovations, with the principles of sustainable development is a clear understanding of the various life cycles that are involved and the interactions between these life cycles[7]. Three distinct life cycles can be distinguished, namely[7]: project life cycle, asset or process life cycle (the life cycle of an implemented technology), and the product life cycle. A project in this context is viewed as a vehicle to implement a capital investment in a new or improved asset or technology. Each of these life cycles consists of various phases (see Figure 2)[7].

The life cycles do nevertheless interact, for example: the product and asset life cycles interact, while the asset and the project life cycle also interact (see Figures 3 and 4)[7]. These interactions of the different life cycles in industry have been described in detail elsewhere[7]. It can thus be concluded that if the sustainability of a project or technology is assessed, the impacts or consequences of the assets and products associated with the project or technology must be included in the assessment.

---

[5] International Institute for Sustainable Development, Deloitte & Touche and the World Business Council for Sustainable Development, 2003. Business strategies for sustainable development: Leadership and accountability for the 90s. Retrieved from http://www.iisd.org/publications/publication.asp?pno=242.

[6] Hill, J., 2001. Thinking about a more sustainable business: An indicators approach. International Journal of Corporate Sustainability; Corporate Environmental Strategy 8(1): 30-38.

[7] Labuschagne, C. and Brent, A.C. 2004, Sustainable Project Life Cycle Management: The need to integrate life cycles in the manufacturing sector. International Journal of Project Management, in press.

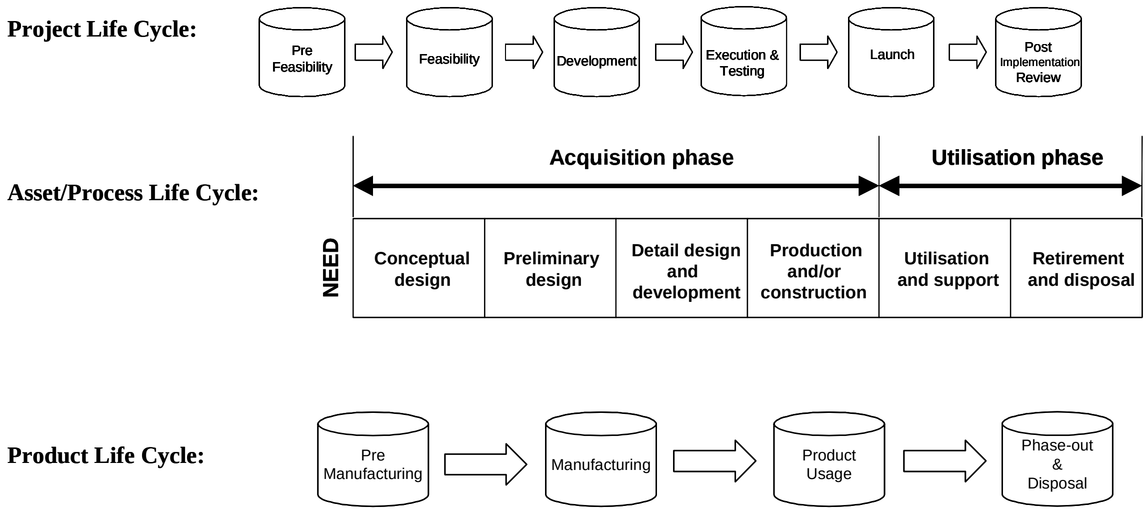

Figure 2: Different life cycles fundamental to operations in industry[7]

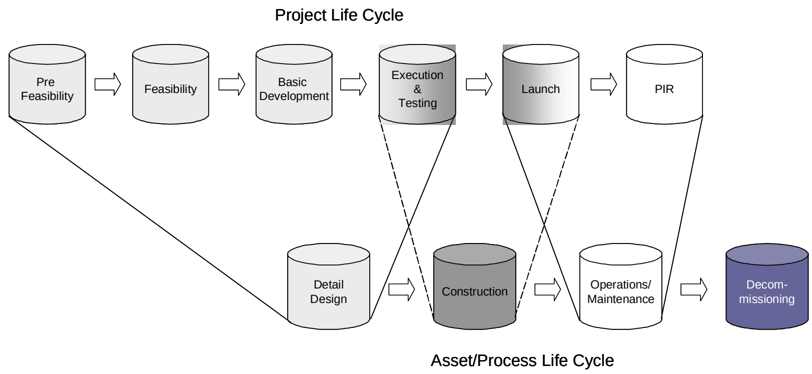

Figure 3: Interaction between the project and asset life cycles[7]

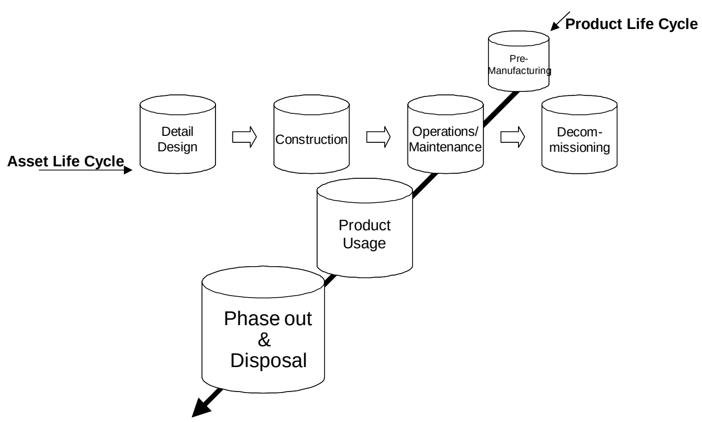

Figure 4: Interaction between the asset and product life cycles[7]

3. A framework of criteria to assess the sustainability of engineering projects and technologies in industry

In order to assess sustainability performances in industry, a framework of appropriate criteria and associated indicators has to be defined. A number of current integrated frameworks, which are used to assess sustainability at an international, national, local or company level, have been reviewed to determine the relevant aspects (or criteria) that should be considered when assessing industry sustainability[8].

The proposed framework of appropriate criteria to assess the sustainability performances of operational initiatives in industry is shown in Figure 5[8]. The framework is divided into different levels to address the separate aspects of corporate responsibility strategy in terms of sustainability. The rationale of these levels has been described in detail elsewhere[8].

From a business perspective, the inclusion or consideration of social aspects in sustainability practices is marginal compared to the environment and economic dimensions[9, 10, 11]. It has further been stated that the current state of development of indicators or measurement procedures of the social performances of industry parallels that of environmental performances approximately 20 years ago[12]. Therefore, the social criteria of the framework were verified by a set of case studies. For each of the three life cycle phases of assets (see Section 2), i.e. construction, operation (which includes the product life cycle) and decommissioning, four case studies were chosen that aimed to determine the significant social impacts that may occur during these life cycle phases:

- The construction of four facilities in the process industry: a mine; an incinerator; petrol filling stations; and a gas pipe line across two countries.
- The operation of four chemical manufacturing facilities of which two are located in South Africa, one in Germany and one in the United States of America.
- The decommissioning of four process facilities: a cyanide manufacturing plant; a fibres manufacturing plant; a mine; and one unit within a process plant.

Project related documentation, pertaining to each of the case studies, were evaluated and personal interviews were held with project responsible individuals. The case studies concluded that certain social impacts are more important in certain phases (see Table 1), while it has been evident that stakeholder participation is crucial in all life cycle phases. A pre-survey has also been conducted in a South African company in the process industry to establish the suitability of the social criteria, as well as the relevance of the criteria in the framework, in terms of sustainable business practices and specifically project Life Cycle Management[13]. The case studies and pre-survey showed that the framework does include all of the relevant social criteria.

---

[8] Labuschagne, C., Brent, A.C. and van Erck, P.G., 2004. Assessing the sustainability performances of industries. Journal of Cleaner Production, in press.
[9] Zadek, S., 1999. Stalking sustainability. Greener Management International 26: 21-31.
[10] Visser, W. and Sunter, C., 2002. Beyond reasonable greed: Why sustainable business is a much better idea. Human & Rousseau & Tafelberg, Cape Town, South Africa.
[11] Roberts, S., Keeble, J. and Brown, D., 2002. The business case for corporate citizenship. Arthur D. Little, Cambridge, United Kingdom.
[12] Ranganathan, J., 1998. Sustainability rulers: Measuring corporate environmental and social performances. Sustainable Enterprise Perspectives, World Resources Institute Publication.
[13] Labuschagne, C. and Brent, A.C., 2004. Sustainable Project Life Cycle Management: Aligning project management methodologies with the principles of sustainable development. Project Management South Africa conference proceedings, Johannesburg, South Africa.

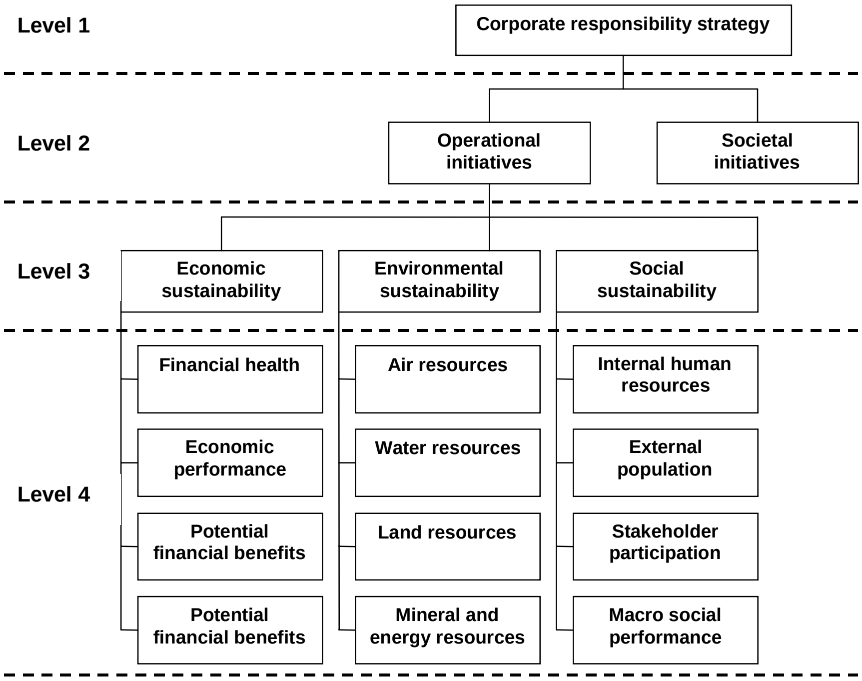

Figure 5: Framework to assess the sustainability of engineering projects and technologies

Table 1: The most important social criteria affected by the different asset life cycle phases

Construction	Operation	Decommissioning
• Employment Opportunities **(Internal Human Resources)** • Sensory Stimuli and Community Cohesion **(External Population)**	• Sensory Stimuli (External Population)	• Employment Opportunities **(Internal Human Resources)** • Economic Welfare **(External Population)**

4. Sustainable development indicators or assessment procedures

The identification of suitable indicators to measure the impacts of an operational initiative, i.e. an undertaken project or technological innovation, including the associated asset and product life cycles, on the three main sustainability dimensions (see Figure 5) is dependent on the following three important points[7, 8]:

- The kind of information that is available at the point of assessing the sustainability performance of a specific operational initiative. For example, considering the life cycle of a technology development project in the process industry, detailed data may not exist in the early stages of the project on which to base an assessment, but may be available at later decision gates in the project appraisal process. Also, additional information gathering activities might have to be executed during individual phases in order to obtain the necessary sustainability data that is required by the indicators.
- The scientific methodology to translate the operational initiative information. There is currently no consensus on the exact procedure to assess the environmental performances of operational activities. However, work is ongoing in this field and methodologies have been proposed. With respect to the social dimension, there is little agreement on which criteria should be considered for social performances evaluations and methodologies are currently not practical for industry applications and business practices. In contrast, the methodologies for most of the sub-criteria of the economic dimension are reasonably well defined.

- The preferences of the specific project appraisers. Two approaches are currently under debate. On the one hand all impacts could be translated into financial terms[14], which is often understandable by decision-makers. On the other hand, it is difficult, if not impossible, to place an economic value on all environmental and social impacts[15], and a qualitative route with decision analysis techniques, e.g. Multi-Criteria Decision Analysis (MCDA), could be used[16]. In some cases, a combination of these two approached have been proposed[17].

In terms of the latter, two approaches are discussed in more detail for the environmental and social dimensions of sustainable development, i.e. a pure monetary evaluation route and a combination of quantitative and qualitative indicators that may be used with decision analysis techniques.

4.1 Sustainability Cost Accounting (SCA) procedure

A Sustainability Cost Accounting (SCA) procedure has been introduced for South Africa, whereby externalities (burdens and benefits) are translated into financial terms to assess the overall sustainability performance of a developed technology[14, 18]. The SCA procedure is similar to the methodology of cost-benefit analysis (CBA), and enables tradeoffs between costs (impacts or deterioration) and benefits (contributions). This is possible as impacts are expressed in a common financial denominator. Whether addressing environmental or social aspects, the SCA procedure adheres to the four steps of an economic CBA that have been distinguished[19, 20]:

1. Making an inventory of (positive and negative) impacts on the environment and society as well as on the economic situation of the company.
2. Determination of the monetary values of the impacts.
3. Discounting long-term effects.
4. Assessing risk and uncertainty in case probabilities can be assigned to the likelihood that an event (industrial accident) will occur, or little is known about future impacts and no probabilities can be assigned.

The fourth step is specific with respect to the evaluated technology and the industry sector. For this reason it is not explicitly addressed in the generalised Sustainability Cost Accounting (SCA) procedure. The environmental and social indicators that have been developed, with respect to determining the monetary values of impacts and adopting discount rates for long-term impacts, for the criteria at level 4 of the framework (see Figure 5) are summarised in

---

[14] Van Erck, R.P.G., 2003. A monetary evaluation of the sustainability of GTL fuel production in South Africa. Master's thesis, Faculty of Technology Management, Technical University Eindhoven, the Netherlands.
[15] Jansen, R., 1992. Multi-objective decision support for environmental management. Kluwer Academic Publishers, Dordrecht, Germany.
[16] Petrie, J., Basson, L., Stewart, M., Notten, P. and Alexander, B., 2001. Decision making for design of cleaner processes: A Life Cycle Management perspective. Proceedings of the First International Conference on Life Cycle Management: Bridging the Gap between Science and Application, Copenhagen, Denmark.
[17] Winpenny, J.T., 1991. Values for the environment: A guide to economic appraisal. HMSO, London, United Kingdom.
[18] Brent, A.C., van Erck, R.P.G. and Labuschagne, C., 2004. A Sustainable Cost Accounting (SCA) methodology for process industry projects in developing countries: A South African case study. Presentation at the annual Environmental Management Accounting Network (EMAN) conference, Lueneburg, Germany.
[19] Blignaut, J.N., 1995. Environmental accounting in South Africa. Doctoral thesis, University of Pretoria, Pretoria, South Africa.
[20] Van Pelt, M.J.F., 1993. Ecologically sustainable development and project appraisal in developing countries. Ecological Economics 7: 19-42.

Tables 2 and 3[21]. The tables provide the costs (of impacts) in the South African currency (for the year 2002), i.e. the Rand (R), for direct use in the South African industry.

A case study has been used to demonstrate the SCA procedure, which considers the operation of a hypothetical Gas-to-Liquid (GTL) fuel-manufacturing facility at a specific location in South Africa[14, 18, 22]. The SCA indicators show that the negative environmental impacts associated with the GTL technology outweigh the internal economic benefits for the company. However, a net positive social beneficiation is associated with the technology, which decision-makers should consider with respect to the overall sustainability of the technology.

The SCA procedure shows certain limitations. Firstly, the concept of sustainability cannot be expressed in monetary terms in a comprehensive manner. Thereby, not all of the criteria (see Figure 5) that are considered relevant to assess sustainability performances can be measured. Secondly, the uncertainty of the data that is obtained, and on which the SCA assessment is based, may strongly influence the usability of a sustainability performance assessment's results. However, this does not mean that the methodology is incapable of improving the understanding of a technology's sustainable performance, i.e. the criteria that are measured are all considered relevant for the assessment of a technology's sustainability.

Table 2: The environmental indicators that are used in the SCA procedure[14, 21]

Main criteria	Sub-criteria	Indicator	Cost (2002)	Comments
Air resources	Regional pollution	Impacts on human health (in R_{2002}/kg) due to: SO_2, NO_x, Heavy metals, PM_{10}, Photochemical ozone	Specific values for pollutants	Based on a population density of 80 inhabitants/km^2
		Impacts on buildings (in R_{2002}/kg) due to SO_2	R 2.03 per kg of pollutant	Based on a population density of 80 inhabitants/km^2
		Impacts on crops (in R_{2002}/kg) due to Photochemical ozone	Specific values for pollutants	Based on a population density of 80 inhabitants/km^2
	Global pollution	Impacts (in R_{2002}/kg) due to Greenhouse Gases (equivalent CO_2)	R 0.22 per kilogram of CO_2 equivalent	Damage costs are based on the lower global estimates of the European Commission
Water resources	Water use	Difference between opportunity costs and water price	R 1.99/m^3	Estimate based on difference between opportunity costs and water price
	Water pollution		Negligible	Based on willingness to pay and is considered negligible
Land resources	Land use	Opportunity costs for the total area affected	Specific for types of land-use	Based on the specific land type that is affected
	Land pollution	Remedy costs	Negligible	Based on willingness to pay and is considered negligible
Mined abiotic resources	Minerals and energy resources	Cost of economic depreciation of non-renewable resources	Calculated user costs of specific natural resources	Discount rate of 4% for South African setting

[21] Brent, A.C., van Erck, R.P.G. and Labuschagne, C., 2004. Sustainability Cost Accounting: Part 1 – A monetary methodology to evaluate the sustainability of technologies. International Journal of Technology Management, in review.
[22] Brent, A.C., van Erck, R.P.G. and Labuschagne, C., 2004. Sustainability Cost Accounting: Part 2 – A case study to assess the introduced monetary methodology for technology management. International Journal of Technology Management, in review.

Table 3: The social indicators that are used in the SCA procedure[14, 21]

Main criteria	Sub-criteria	Indicator	Comments
Internal human resources	Employment stability	Expenses on: Wages; Unimployment Insurance Fund (U.I.F.); Life insurance; Medical aid	Adopt expenditures from annual financial reports. Based on expected number of employees required to manufacture a product or provide a service
	Health and safety	Cost (to a company) of medical mortality/morbidity	Damage costs of mortality and morbidity of employees resulting from their manufacturing or service provision activity for a newly developed technology
	Capacity development	Investments in training, education and R&D	Adopt expenditures from annual (financial) reports
External population	Human capital	Investments in medical and educational facilities directly attributable to an introduced technology	Adopt expenditures from annual reports or project specific publications
	Community capital	Real estate price changes in the area where a technology is introduced	Base estimates on real estate prices provided by local real estate agents and total real estate value provided by municipalities
Stakeholder participation	Stakeholder participation	Expenses on Environmental Impact Assessments	Company-specific information
Macro-social performance	Socio-economic performance	Tax on profits Tax on wages Other taxes	Adopt expenditures from annual financial reports. Based on expected profit and number of employees related to a manufactured product or provided service
	Socio-environmental performance	Expenditure on monitoring	Expected investment in regional pollution monitoring due to the introduced technology

4.2 Multi Criteria Decision Analysis with Environmental Resource Impact Indicators (RIIs) and Social Impact Indicators (SIIs)

The advantages of Multi Criteria Decision Analysis (MCDA) techniques are that each decision criteria receives due consideration without necessarily converting it to a common scale such as a monetary value. The value that these techniques can contribute to strategic decision-making should not be ignored[16] and therefore a second approach to measure the sustainability impacts and incorporate it into decision-making is proposed. This approach thus proposes the use of a MCDA technique (for example the Analytical Hierarchical Process) to establish subjective weighting values for the different indicators (at level 4 of Figure 5) of the social, economic and environmental dimensions, and then to use the weighting values together with the indicator values in internal decision-making or for evaluation purposes. As far as indicators are concerned, the economic dimension has indicators (e.g. Return on Investment), which can be used directly. However, two procedures that are strongly based on LCA principles are currently used to derive indicators for the environmental and social dimensions.

a) Environmental Resource Impact Indicators

A quantitative procedure to calculate environmental Resource Impact Indicators (RIIs) has been introduced, following the conventional Life Cycle Impact Assessment (LCIA) methodology[23]. Thereby, the following equation is applied to calculate the environmental impact indicators of an operational initiative on the level 4 criteria of the framework (see Figure 5):

[23] Brent, A.C., 2004. A Life Cycle Impact Assessment procedure with resource groups as Areas of Protection. International Journal of Life Cycle Assessment 9(3): 172-179.

$$RII_G = \sum_{C} \sum_{X} Q_X \cdot C_C \cdot N_C \cdot S_C \qquad (1)$$

Where: RII_G = Resource Impact Indicator calculated for a main resource group (air, water, land, or mined abiotic) through the summation of all impact pathways of LCI constituents on the resource group

Q_X = Quantity of LCI constituent X released to or abstraction from a resource group

C_C = Characterisation factor for a midpoint impact category C (of constituent X) within the pathway

N_C = Normalisation factor for the midpoint impact category based on the ambient environmental quantity and quality objectives, i.e. the inverse of the ambient target state of the impact category

And; $S_C = \frac{C_S}{T_S}$ = Significance (or relative importance) of the midpoint impact category based on the distance-to-target method, i.e. current ambient state (C_S) divided by the target ambient state (T_S)

b) Social Impact Indicators

A similar approach is proposed for the social dimension of sustainable development. However, in order to follow such an approach the following must be defined:

- The interventions of an operational initiative, including the associated product life cycle, on the social dimension, i.e. the social LCI of an operational initiative.
- The classified midpoint categories, with respective characterisation factors for the social LCI constituents.
- Measurement or equivalence units for the classified midpoint categories.
- Normalisation values for the social midpoint categories based on the target background social footprint in the society where an operational initiative will occur.
- Significance factors that are a function of the current background social footprint compared to the target background social footprint in the society where an operational initiative will occur.

Midpoint categories have been defined by mapping a list of identified possible social interventions in the process industry (which was a result of the case studies discussed in Section 3) with the criteria at the different levels of the sustainability performances assessment framework[8]. Three measurement methods are proposed to express these defined midpoint categories in equivalence units (see Table 4):

- Established risk assessment approaches, which require a subjective evaluation of the probability of occurrence, the projected frequency of the occurrence, and the potential intensity thereof;
- Quantitative evaluation approaches, including, but not limited to, costs (see Section 4.1) and direct measurements in society; and
- Qualitative evaluation approaches, which require appropriate subjective scales and associated guidelines, and have been proposed for the industrial ecology and streamlined LCA disciplines.

From the definition of the midpoint categories it is evident that the normalisation and significance steps will be constraint by what is practicably measurable within a society where an operational initiative (from an industry perspective) will typically occur. In this regard the availability of information will most definitely differ between developed and developing countries. Furthermore, the projection of the social interventions of a project or technology may be problematic or at least differ from case to case.

Table 4: Midpoint categories and measurement methods to express equivalence units

Social Impact Indicators (SIIs)	Midpoint category	Measurement methods to establish equivalence units
Internal human resources	Permanent internal employment positions	Quantitative
	Internal Health and Safety situation	Risk
	Knowledge level / Career development	Quantitative
	Internal Research and Development capacity	Quantitative
External population	Comfort level / Nuisances	Risk
	Perceived aesthetics	Qualitative
	Local employment	Quantitative
	Local population migration	Qualitative
	Access to health facilities	Quantitative
	Access to education	Quantitative
	Availability of acceptable housing	Quantitative
	Availability of water services	Quantitative
	Availability of energy services	Quantitative
	Availability of waste services	Quantitative
	Pressure on public transport services	Quantitative
	Pressure on the transport network / People and goods movement	Quantitative
	Access to regulatory and public services	Quantitative
Stakeholder participation	Change in relationships with stakeholders	Qualitative
Macro-social performance	External value of purchases / supply chain value	Quantitative
	Migration of clients / Changes in the product value chain	Qualitative
	Improvement of socio-environmental services	Quantitative

5. Conclusions

This paper has provided an overview of the aspects of, or different life cycles associated with, a technology or project that must be assessed internally. Furthermore, a framework of sustainable development criteria, relevant for operational initiatives in industry, has been defined for such internal assessments. Two types of sustainable development indicators or assessment procedures have also been introduced and discussed, specifically for the environmental and social dimensions of sustainability.

One procedure attempts to convert the criteria into monetary terms. However, problems have been identified with this approach and further case studies are required in order to establish the appropriateness of such a procedure for decision-makers. The second procedure proposes to apply MCDA techniques with calculated indicators. The calculation of these indicators follows normal LCIA methodologies, i.e. a midpoint category approach. Social midpoint categories have subsequently been introduced and further research is now required in order to determine which midpoint categories should form part of a sustainable project or technology LCM procedure. Firstly, a survey in the South African industry will establish which social criteria are relevant at project level and which should rather form part of a corporate governance framework. Secondly, the application of the Delphi technique will establish which of the midpoint categories can be practically measured in the process industry, i.e. suitable information is available from within projects and the external environment. Lastly, case study information from a set of industry case studies (see Section 3) will determine the ease of calculating the midpoint category values and determine whether the values are meaningful for decision-makers.