International Association for Management of Technology
IAMOT 2007 Proceedings

SUSTAINABLE DEVELOPMENT: A CONCEPTUAL FRAMEWORK FOR THE TECHNOLOGY MANAGEMENT FIELD OF KNOWLEDGE AND A DEPARTURE FOR FURTHER RESEARCH

ALAN C BRENT

Graduate School of Technology Management, University of Pretoria
Natural Resources and the Environment, CSIR

MARTHINUS W PRETORIUS

Graduate School of Technology Management, University of Pretoria
Pretoria, 0002, South Africa
alan.brent@up.ac.za

The complexity of integrating the concept of sustainable development and the reality of technology or innovation management practices has been argued. The purpose of the research was to establish a conceptual framework of the technology management field of knowledge and identify the departure point for further research in terms of incorporating the concept of sustainable development into the field. From a review of the literature it is concluded that sustainability aspects are not addressed adequately in technology management theories and practices. The subsequent conceptual framework defines the context better in which sustainable technology management should occur. Emerging technology management practices related to sustainable development do emphasise the focus on technology strategy, selection and transfer, especially between developed and emerging economies. At the core of these issues lies technology assessment that also forms part of other technology frameworks and methodologies. For the departure point for further research it is therefore recommended to concentrate on the development of technology assessment methods, based on the modification of the Technology Balance Sheet, Income Statement and Space Map analytical techniques, that incorporate the dynamic interactions between nature and society that is researched in the newly established field of sustainability science.

Keywords: Sustainable Development; Technology Management; Technology Assessment; Sustainability Science.

Introduction

The World Commission on Environment and Development (WCED)'s report in 1987 is viewed as a major political turning point for the concept of sustainable development (Mebratu, 1998). Since then the influence of the concept has increased extensively and it features more and more as a core element in policy documents of governments and international agencies (Mebratu, 1998). The World Summit on Sustainable Development (WSSD) in 2002 highlighted this growing recognition of the concept by governments as well as businesses at a global level (Labuschagne and Brent, 2005). This need to incorporate the concept of sustainable development into decision-making, combined with the World Bank three-pillar-approach to sustainable development (World Bank, 2001), resulted in the popular business term "triple-bottom-line decision-making".

The concept of sustainability and sustainable development may be understood intuitively, but it remains difficult to express in concrete, operational terms (Briassoulis, 2001). However, many agree that sustainable development is about achieving environmental, economic, and social welfare for present as well as future generations (Azapagic and Perdan, 2000). From a governmental perspective this can be at national and global levels (UNCSD, 2001). From an organizational perspective this can be at project (Labuschagne *et al.*, 2005a) and technology (Brent *et al.*, 2006; 2007) levels. In some cases stakeholders specifically require that environmental, economic, and social goals must be met across all levels of development. Sustainable development has subsequently been conceptualised as a state of dynamic equilibrium between societal demand for a preferred development and the supply of environmental and economic goods and services needed to meet this demand (Briassoulis, 2001). Systems approaches have been proposed to consider strategic sustainable development planning in different sectors (Robèrt *et al.*, 2002; Labuschagne *et al.*, 2005b). But the intricate relationships between the three dimensions of sustainable development, i.e. environmental, economic and social welfare, have been difficult to model within the concept of a clear absolute technological system (Brent *et al.*, 2006; 2007). Specifically, trade-offs between the three dimensions of sustainable development may not be possible to quantify as the benefits cannot be measured. Proposals for these trade-offs can be referred to as 'weak', i.e. indirectly indicating sustainability (Hanley *et al.*, 1997; Rennings and Wiggering, 1997; Atkinson, 2000).

Consensus on the general objectives and basic principles of sustainable development may be obtained in theory. But consensus on the details of how to achieve sustainable development or maintain sustainability is difficult to obtain in practice. This difficulty can be attributed to the variety of perceptions on specific socio-cultural and political contexts that change over time (Briassoulis, 2001; Brent *et al.*, 2005a). To this end, the complexity of integrating the concept of sustainable development and the reality of technology or innovation management practices has been argued (Coles and Peters, 2003). The problem lies with the required amalgamation of the:

(i) Traditional sustainability sciences of environmental and social assessment, and the associated Integrated Environmental Management tools.
(ii) Conventional and resource- or environmental-focused economic sciences, and the associated tools such as Life Cycle Costing.
(iii) The technology management theories and associated applications such as technology forecasting and roadmapping, and transfer.

From a research perspective the following main question was subsequently posed: Are sustainability aspects addressed adequately in technology management theories and practices? In other words, has technological research progressed into the field of sustainability science, as has been suggested (Kates *et al.*, 2001)? The research question focuses on mainly those large-scale technologies, i.e. technologies that can only be added in discreet sized lumps (Murto, 2000), and which are highly dependent on, or may pose risks to, the natural resource base of countries and regions (Cooney, 2004).

Objectives of the paper

The primary objective of this paper is to establish a conceptual framework of the technology management field of knowledge, and coupled tools and methodologies, as it relates to sustainable development. The secondary objectives are to introduce a criteria framework of what sustainable development entails in different resource-based sectors where technology management occurs, e.g. the manufacturing, energy, and agricultural sectors, and to provide insight into how sustainability aspects may be measured effectively as part of technology management practices in these sectors.

From these objectives the paper aims to identify the departure point for further research in terms of incorporating the concept of sustainable development into the technology management field of knowledge, which is a specific agenda that may differ significantly from other technology management orientated research themes (Pilkington and Teichert, 2006).

Methods

The primary objective of the paper was addressed by first considering the:

(i) Management of Technology (MOT) body-of-knowledge (BoK) process, which has been initiated by the International Association for Management of Technology (IAMOT, 2006), and specifically a survey on a Template for Graduate Programs and an analysis of the results of a survey of 148 Technology Management or MOT graduate programs (Portland State University, 2003).

(ii) Engineering and Technology Management Education and Research Council's identification of related research areas (ETMERC, 2006).

The Technovation journal was then searched for papers relating to tools and methodologies of technology management in general, and on sustainable development, but relating to technology management. The keywords of 'technology management tools', 'technology management methodology' and 'sustainable development' were used in the review (see Table 1). Furthermore, a boolean search was conducted in multiple journal databases for the keywords 'technology management' and 'sustainable development' (see Table 1).

The IAMOT BoK survey, the ETMERC identification of related research areas, and the Technovation papers on 'technology management tools' and 'technology management methodology' were used to construct a mind map of the technology management field of knowledge (see Figure 1), which is downloadable from the internet (University of Pretoria, 2006). Mind maps are especially useful as support for intuitive-type research to highlight casual connections between different aspects (Monaghan, 2003). In Figure 1 overlaps between the IAMOT and ETMERC defined areas are shown with graphical links (left-hand side of Figure 1). The linkages between defined technology management tools and methodologies, and associated applications (right-hand side of Figure 1), and the IAMOT and ETMERC areas are shown with numeric keys. The specific linkages between the core technology management areas and sustainable development are emphasised with shadings.

The additional literature on 'technology management' identified a conceptual framework that could be improved in the context of sustainable development. The obtained literature on 'sustainable development' was used to determine how the linkages between the core technology management areas and sustainable development occur in practice.

Table 1. Journals and papers relating to technology management theories and practices, and technology management orientated sustainable development

Journal	Keywords	References
Technovation	Technology management tools	Phaal *et al.*, 2006 Maine *et al.*, 2005 Brady *et al.*, 1997
	Technology management methodology	Liao, 2005 Jacob and Kwak, 2003
	Sustainable Development	Demaid and Quintas, 2006 Fahmy, 2005 Gerstlberger, 2004 Watanabe et al., 2003 Harris and Khare, 2002 Lambert and Boons, 2002
International Journal of Technology Transfer & Commercialisation (ABI Inform)	Sustainable Development AND Technology Management	Momaya. 2005
International Journal of Services Technology and Management (CSA Illumina)		Banwet et al., 2003
International Journal of Biotechnology (CSA Illumina)		Hamilton, 2001
International Journal of Technology Management (CSA Illumina)		Bowonder and Miyake, 2000
Technological Forecasting and Social Change (CSA Illumina)		Sharif, 1992
International Journal of Technology Management (SCOPUS)		Khalil and Ezzat, 2005 Phaal *et al.*, 2004

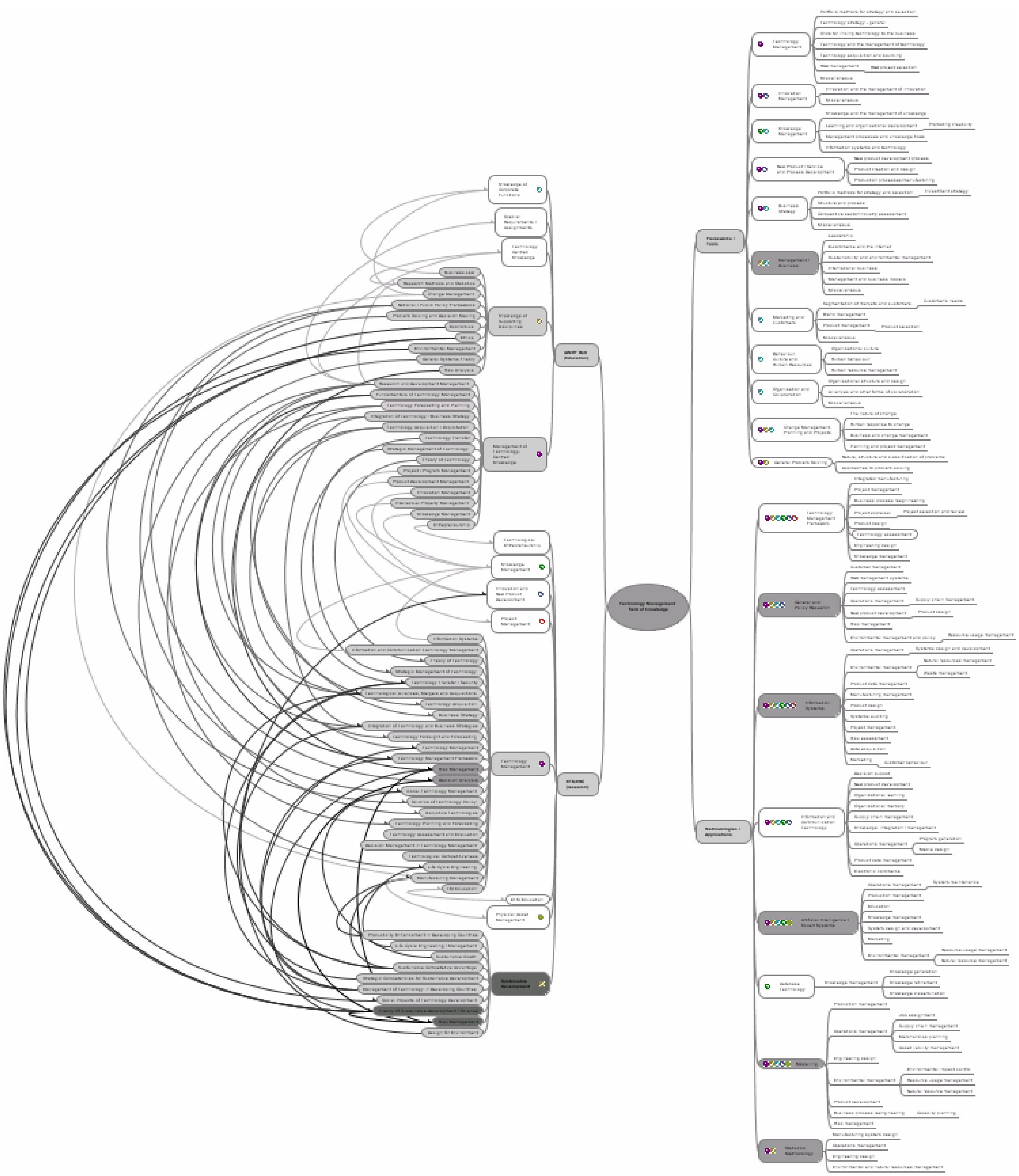

Figure 1. Mind map of the Technology Management field of knowledge

The detailed mind map can be downloaded from the website of the Department of Engineering and Technology Management of the University of Pretoria (2006).

Discussion

An existing conceptual framework for technology management

A conceptual framework, which is the intent of this paper, supports understanding of an issue or area of study, provides structure, communicates relationships within a system for a defined purpose, and supports decision making and action (Phaal *et al.*, 2004). Such a framework has been introduced (see Figure 2), which is aimed at the firm level (Phaal *et al.*, 2004). The system, within which it applies, is that of a manufacturing business. The framework aims to support understanding of how technological and commercial knowledge combine to support strategy, innovation and operational processes in a firm, in the context of both the internal and external environment.

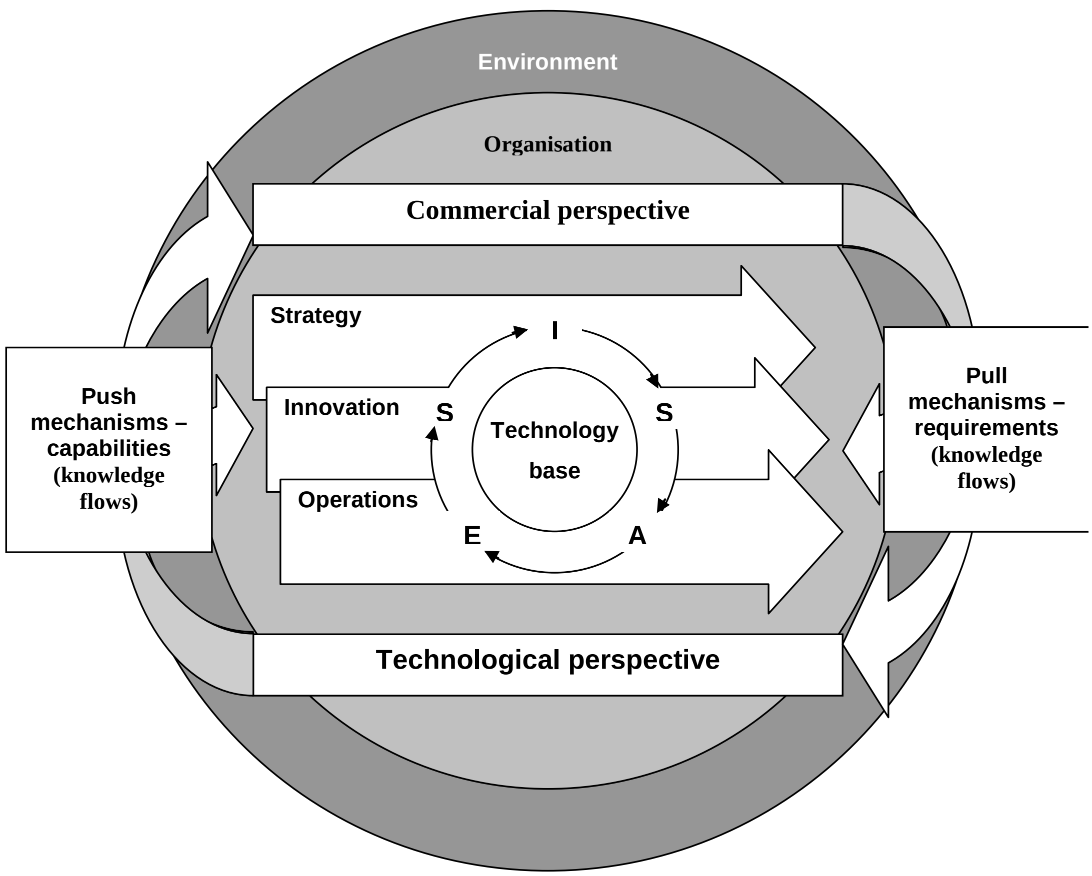

Figure 2. Conceptual technology management framework at firm level (adopted from Phaal et al., 2004)

The framework emphasises the knowledge flows that must occur between commercial and technological functions of a firm, and that an appropriate balance must be obtained between push (firm capabilities) and pull (market requirement) mechanisms (Phaal *et al.*, 2004). However, these mechanisms are defined from an internal-to-external perspective. The framework does not accentuate the external-to-internal drivers of sustainable development, which have been noted (Labuschagne and Brent, 2005a), especially for firms that develop and deploy large-scale resource-oriented technologies (see Figure 3). From a sustainable development perspective it is required to expand the 'environment' component of the conceptual framework.

Furthermore, and especially for large-scale resource-oriented technologies, the system must be extended beyond the firm level, i.e. the life cycle of the technology (or asset) and the life cycle of the associated product value chain must be considered (Brent *et al.*, 2005b; 2007). Such an extended life cycle system is illustrated in Figure 4.

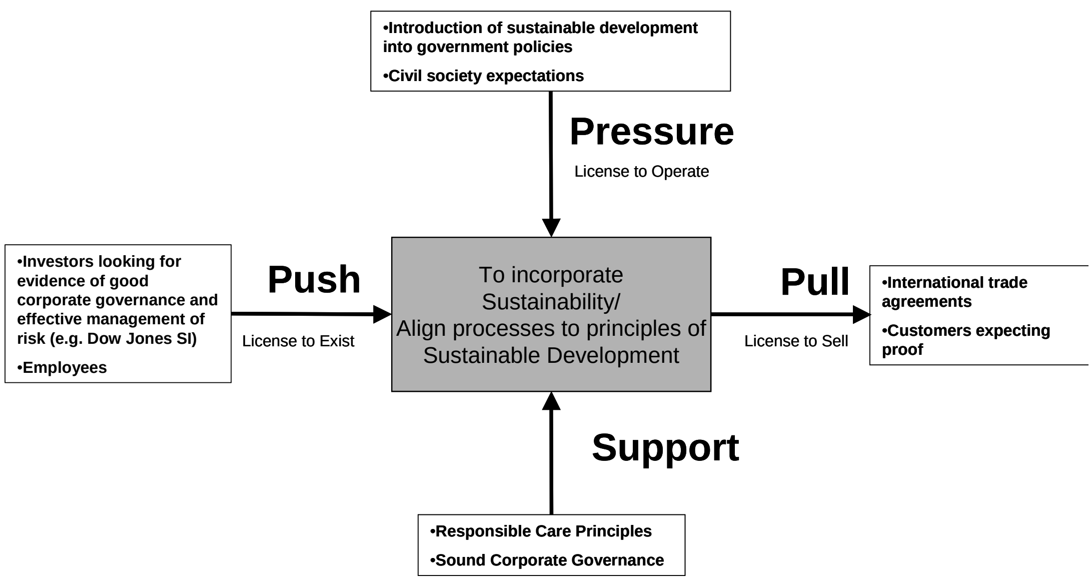

Figure 3. Drivers of sustainable development (adopted from Goede as cited in Labuschagne and Brent, 2005)

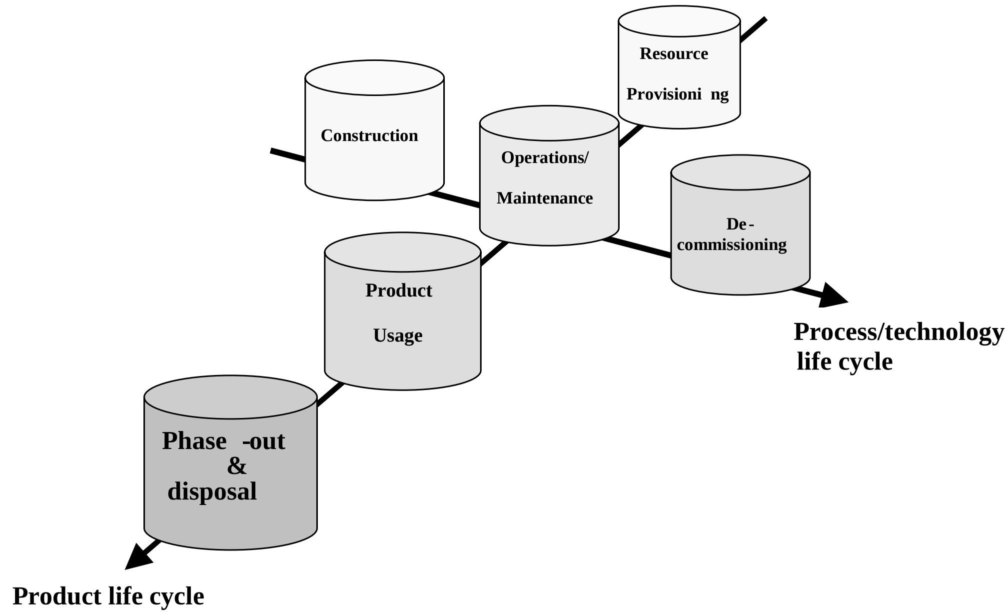

Figure 4. Life cycle system for large-scale resource-oriented technologies (adopted from Brent et al., 2005b; 2007)

Defining a conceptual technology management framework in the context of sustainable development

Many different criteria frameworks that aim to address the concept of sustainable development in different sectors are available in the literature. From an analysis of the different approaches, a framework has been introduced (Labuschagne *et al.*, 2005b) that focuses on large-scale resource-oriented technologies (see Figure 5). The framework emphasises that the operational initiatives in industry must be evaluated separately in terms of internal and external economic, social and environmental performances. However, the internal operational sustainability must also be ensured, e.g. technology management practices, and a fourth dimension of sustainable development has been suggested (Labuschagne *et al.*, 2005b; Mulder and Brent, 2006). Therefore, it is proposed that technology management, as it relates to sustainable development, should be conceptualised as a triangular-based pyramid (see Figure 6). The three conventional dimensions of sustainable development form the base or foundation of the pyramid, and supports sustainable technology management practices at the top of the pyramid.

The conceptual framework indicates two planes of influence. First, technology management practices (at the firm level) influence other internal operations, but sustainable development aspects, e.g. economic forces, natural resource constraints, and social behaviour, may also influence internal operations. In turn, internal operations do exercise influence on different sustainable development aspects. Similarly, there is interaction between internal operational initiatives, the technology and product life cycle phases outside the firm level, and sustainable development aspects.

It has been stated that conceptual frameworks exist largely in the mind and require practical devices to ‘interface’ with the real world, in terms of both the development (induction) and application (deduction) of frameworks (Phaal *et al.*, 2004). The devices, i.e. tools and methodologies, depicted on the right of the technology management mind map (Figure 1) are primarily concerned with the interfaces between two planes of the conceptual framework. This is reflected in the defined research and education focus areas of IAMOT and ETMERC.

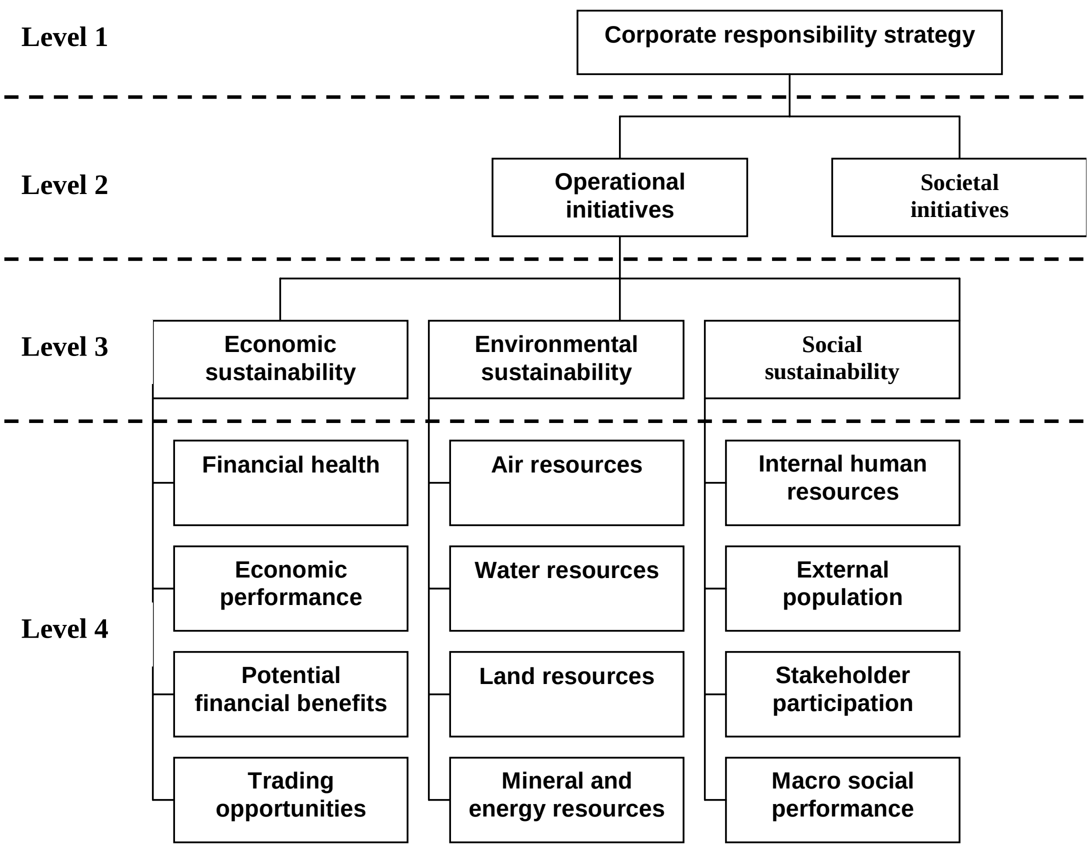

Figure 5. Framework to evaluate the sustainability performances of operational initiatives (adopted from Labuschagne *et al.*, 2005b)

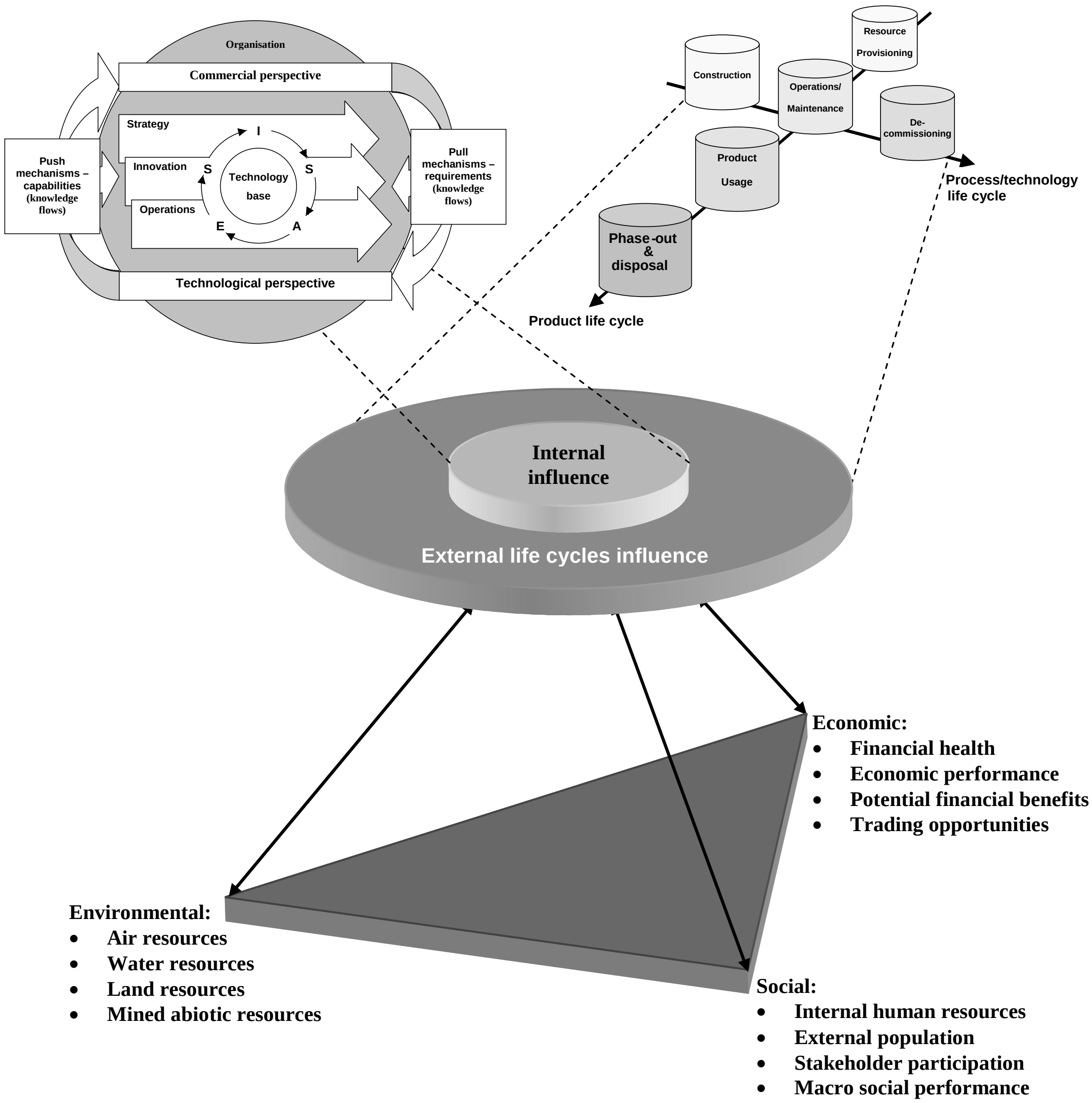

Figure 6. Conceptual framework for technology management in the sustainable development context

Interfaces between the planes and the sustainable development aspects have been considered in theory, albeit to a lesser extent. Table 2 summarises the obtained literature that deals with such interfaces. In these cases the technology management research and applications were mainly associated with the sub-areas of risk management and decision-analysis or support, and is highlighted in Figure 1 (dark shading).

Table 2. Current technology management research and applications in relation to sustainable development

Reference	Description of paper focus
Demaid and Quintas, 2006	The uncertainty associated with the changing legal and ethical imperatives of sustainable development and the related additional complexity of knowledge management in a specific sector; the similarities between the fields of sustainable development and risk are specifically highlighted.
Fahmy, 2005	Technological trends in specific sectors due to sustainable development pull and push drivers with a subsequent strategic plan and policy advice for decision-makers.
Gerstlberger, 2004	Systematic design of regional innovation systems for policy support, whereby the multidimensional aspects of sustainable development aspects are considered for effective, sustainable knowledge transfer in networks.
Watanabe *et al.*, 2003	Policy options to substitute technologies in a specific sector for competitive advantage; sustainable development, from an ecosystem perspective, is used as basis to formulate an approach for competitive innovation.
Harris and Khare, 2002	Strategy development for a specific sector due to sustainability pull and push drivers; sustainable development risk are identified that decision-makers must consider for the long-term survival of the sector.
Lambert and Boons, 2002	Societal and environmental problems related to mixed industrial parks, i.e. an extension of the industrial symbiosis concept, are identified, and solutions are proposed to ensure the continuity and sustainability of these parks.
Momaya. 2005	Strategic management of technology to sustain the competitiveness of organisations; sustainable development is synonymous with management performance and competitiveness in terms of productivity, growth, returns and market capitalisation.
Banwet *et al.*, 2003	Technological competitiveness must be achieved to realise sustainable development, and the internal processes and assets that derive performances are important for decision-makers; no emphasis is placed on external drivers.
Hamilton, 2001	Defining characteristics of technological trends and response firms to propose changes in management practices for effective technology transfer.
Bowonder and Miyake, 2000	Combining knowledge management and ecosystem theory concepts to sustain competitive advantage in an uncertain business context.
Sharif, 1992	Increasing international cooperation to ensure the advancement and spread of technology that is economically efficient, commercially attractive, and environmentally sound, and that leads to self-reliance; technology-oriented policies are addressed.
Khalil and Ezzat, 2005	Globalisation, competitiveness, and the risk of marginalisation of developing nations; responses in public policy are highlighted, with emphasis on human resource development.

Emerging technology management practices related to sustainable development

It has been noted that, as a research area, technology management is extremely diverse (Pilkington and Teichert, 2006). This is emphasised in the mind map of Figure 1. Furthermore, in the sustainable development context, technological research is viewed as one of the four branches of sustainability science (Kates *et al.*, 2001), i.e. concentrating on the design of devices and systems to produce more social goods with less environmental harm. Sustainability science in turn can be defined as the study and integration of particular issues and aspects of radical, systemic approaches to innovation and learning for ecological and social sustainability (Struyf, 2003). The merger of these two fields has led to concepts such as Environmentally Sound Technologies (ESTs), i.e. technologies that have the potential for significantly improved environmental (and social) performance relative to other technologies (IETC, 2003a).

The European Institute for Technology and Innovation Management (EITIM, 2001) states: "technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies (product, process and infrastructural) needed to maintain a market position and business performance in accordance with the company's objectives".

For ESTs, the emphasis is not only on the firm level, but also on the regional, national and international levels (IETC, 2003b). This again stresses the requirement to expand the technological system that is managed, as is shown in the conceptual model (Figure 6), and an adaptation to the EITIM definition is proposed, i.e. technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies (product, process and infrastructure) needed to sustain the competitive advantage of regional sectors in accordance with the sector, regional, national and international sustainable development objectives. A number of cases have been documented in literature that supports the proposed definition of technology management (see Table 3).

Table 3. Emerging technology management research and applications in relation to sustainable development

Reference	Description of paper focus
Grieve, 2004	An accepted strategy for medium- and large-scale industry sectors in less developed countries is identified as capability building for technology options based on technology transfer with the aim of achieving competitiveness in international markets; the 'intermediate technology' approach is also introduced for the clustering of small-scale developments in sectors of the third-world.
Tsoutsos and Stamboulis, 2005	A strategy is suggested that focuses on selected niches with the aim of integrating the innovation dimension into a policy for specific technology options; the growth in successful applications would lead to the development of new industry sectors in countries.
Knot *et al.*, 2001	Strategies for enhancing the flexibility of technological systems, which is increasingly required because of uncertainties and fast developments, to promote alternative technology options and change in industry sectors.
Coles and Peters, 2003	A more informed analysis of technological innovation, and associated options, is suggested for discussions about the future direction of industrial society and subsequent strategies that is required to adapt specific sectors to sustainability requirements.
Bessant and Francis, 2005	Mechanisms are explored for transferring technologies into sectors of developing countries, by first characterising technologies, and then identifying strategies for organisational development to facilitate such transfers.
Malairaja and Zawdie, 2004	Policy issues are discussed that need to be addressed to enhance the effectiveness of the transfer and innovation of specific technologies in sectors of developing countries.
Ayele, 2005	Analysis and strategy of how new technologies can be delivered in specific sectors of developing countries; specifically the transfer of knowledge between sectors and between innovation processes is addressed.
Harris and Pritchard, 2004	Adaptation of a technology transfer model for application at company, network and government level for symbiotic strategy formulation.

Table 3 further shows that the literature on technology management and sustainable development increasingly deals with three main issues:

(i) Integrated strategies across companies, sectors, regions, and, in some cases, across countries.

(ii) Selection of appropriate technological options across companies, sectors, regions and countries.

(iii) The transfer of technologies (and knowledge) across companies, sectors, regions and countries.

A focal point of these three issues is that of technology assessment or evaluation, which also forms part of other technology frameworks and methodologies (see Figure 1). Technology evaluation is one of the most significant techniques in an innovation function, such as technology transfer, and it is best utilized in screening new ideas, assessing innovative or not innovative technologies; it is a set of principles, methods and techniques or tools for effective assessing the potential value of a technology and its contribution to a company's competitiveness and profitability (Bakouros, 2005). Models (Pretorius and de Wet, 2000) and metrics (Geisler, 2002) have been introduced to assist the technology assessment process at firm level. The following statements have been made with regards to the ongoing development of metrics (Geisler, 2002):

(i) Technology is not judged by its existence alone, nor is its mere existence a sufficient condition for successful usage.
(ii) We cannot evaluate technology unless and until we put it in the context of social (and environmental) and economic phenomena.
(iii) Technology is not defined and evaluated by what it is, but by the criteria outside itself – by its actual and potential users.

These statements support the system expansion component of the conceptual framework (Figure 6), and the notion of sustainability performance indicators that have been proposed for technology management purposes (Labuschagne *et al.*, 2005; Brent *et al.*, 2005b; 2007).

Sustainability performance indicators for technology management

General technical, economic, environmental and social indicators have been proposed for technology transfer evaluations (Dunmade, 2002). For large-scale resource-oriented technologies specific sustainability indicators have subsequently been developed, which are described in detail elsewhere (Brent and Visser, 2005; Labuschagne and Brent, 2006; Mulder and Brent, 2006). Although the applications of these indicators do attempt to follow a holistic approach, constraints have been noted where sustainability information is required from parts of the expanded system that is not controlled by the particular technology management decision-makers. Especially in the initial research and development phases of technology management, a set of principles, methods and techniques or tools must be established for effectively assessing the potential value of a technology and its contribution to sustainable development during the market uptake phases of its life cycle (see Figure 7).

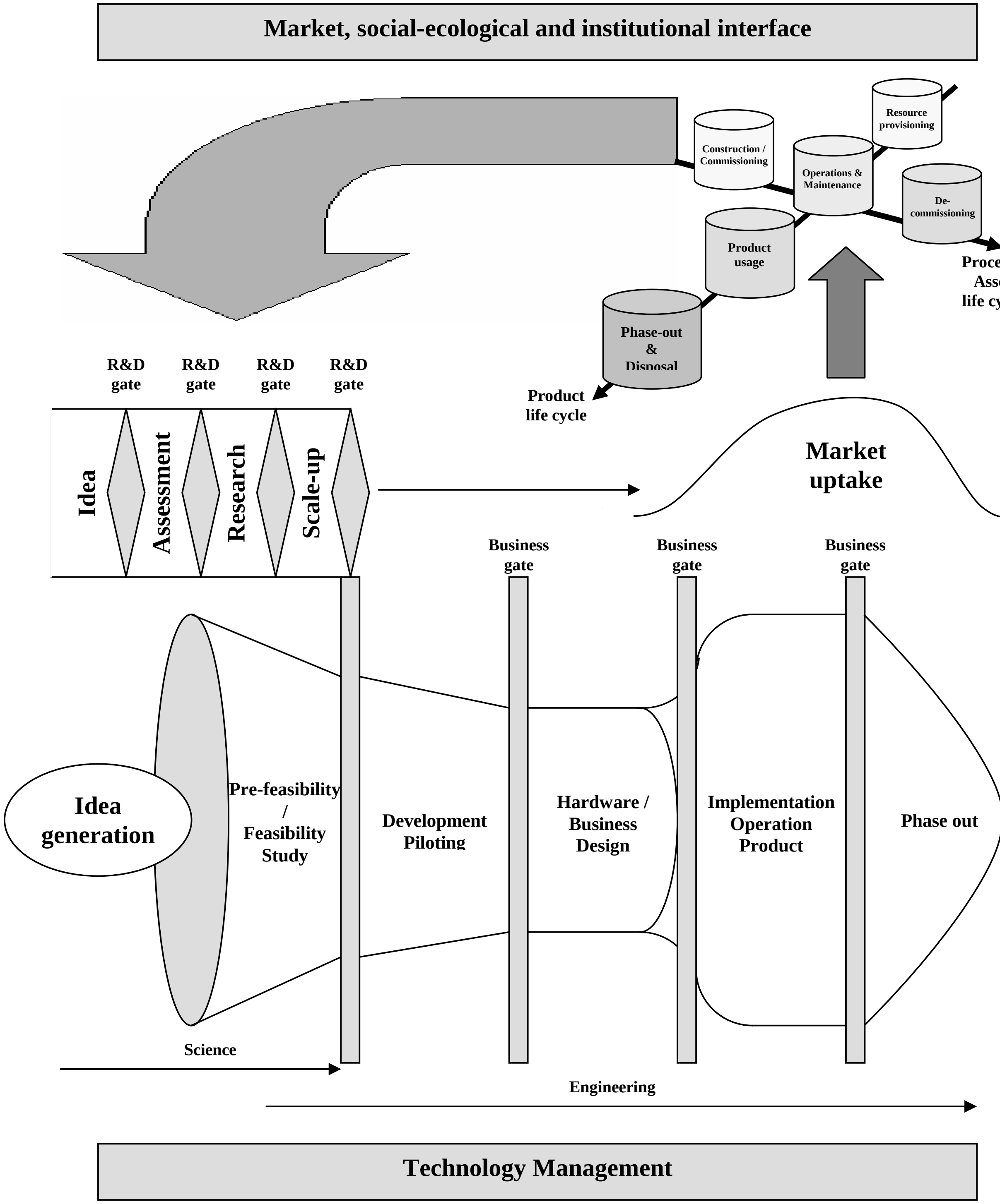

Figure 7. Technology life cycle interventions and associated evaluated systems

Conclusions

The turn of the millennium has seen increasing efforts to align technological research with the emerging field of sustainability science (Clark and Dickson, 2003). However, the field of science and technology for sustainability is in its infancy (AAAS, 2006). From the review of the literature summarised in this paper, it is concluded that sustainability aspects are not addressed adequately in technology management theories and practices. A conceptual framework is subsequently proposed, which is based on an existing framework for technology management, but as the field relates to sustainable development. The framework defines the context better in which sustainable technology management should occur in practice. An expanded system perspective is required, that not only includes the respective technological, operational and business life cycles across companies, sectors, regions and countries, but also the dynamic interaction between macro, meso, and micro economies, societies at large, and the natural environment, as perceived by sustainability science. A modification to the definition of technology management has subsequently been proposed.

The technology management field is extremely diverse, which is illustrated through an introduced mind map. However, emerging technology management practices related to sustainable development do emphasise the focus on technology strategy, selection and transfer, especially between developed and emerging economies. At the core of these issues lies technology assessment, which also forms part of other technology frameworks and methodologies. As a departure point for further research in terms of incorporating the concept of sustainable development into the technology management field of knowledge, it is therefore recommended to concentrate on the development of technology assessment methods, as they are used in technology management practices, which incorporate the intrinsic modelling that is researched in the field of sustainability science. To this end, the modification of the available Technology Balance Sheet, Income Statement and Space Map analytical techniques are currently being investigated, with specific emphasis on the initial research and development phases of technology management.

Ultimately, the challenge lies in the formation and coordination of transdisciplinary research teams (Pohl, 2001) that are required to reach truly sustainable technology management practices.

References

American Association for the Advancement of Science (AAAS), 2006. FORUM: Science and Innovation for Sustainable Development. Website: http://sustsci.aaas.org/, accessed 20 December 2006.

Atkinson, G., 2000. Measuring corporate sustainability. J. Env. Planning and Man. 43 (2), 235-252.

Ayele, S., 2005. Biotechnology generation, delivery and adoption: The case of Bt biopesticide in Eqypt. Int. J. Tech. Man. and SD. 4 (2), 75-91.

Azapagic, A., Perdan, S., 2000. Indicator of sustainable development for industry: A general framework. Trans IchemE 78 (b), 243-261.

Bakouros, Y., 2005. Technology evaluation. Portland International Conference for the Management of Engineering and Technology (PICMET), Portland, Oregon.

Banwet, D.K., Momaya, K., Shee, H.K., 2003. Competitiveness through technology management: an empirical study of the Indian software industry. Int. J. Services Tech. and Man. 4 (2), 131-155.

Bessant, J., Francis, D., 2005. Transferring soft technologies: Exploring adaptive theory. Int. J. Tech. Man. and SD. 4 (2), 93-112.

Bowonder, B., Miyake, T., 2000. Technology management: A knowledge ecology perspective. Int. J. Tech. Man. 19 (7), 662-684.

Brady, T., Rush, H., Hobday, M., Davies, A., Probert, D., Banerjee, S., 1997. Tools for technology management: An academic perspective. Technovation 17 (8), 417-426.

Brent, A.C., Heuberger, R., Manzini, D., 2005a. Evaluating projects that are potentially eligible for Clean Development Mechanism (CDM) funding in the South African context. Env. and Dev. Econ. 10 (5), 631-649.

Brent, A.C., van Erck, R.P.G., Labuschagne, C., 2005b. A sustainability cost accounting methodology for technology management in the process industry. International Association for the Management of Technology (IAMOT), Vienna, Austria.

Brent, A.C., Visser, J.K., 2005. An Environmental Performance Resource Impact Indicator for Life Cycle Management in the manufacturing industry. J. Clean. Prod. 13 (6), 557-565.

Brent, A.C., van Erck, R.P.G., Labuschagne, C., 2006. Sustainability Cost Accounting: Part 1 - A monetary procedure to evaluate the sustainability of technologies in the South African process industry. South African J. Industrial Eng. 17 (2), 35-51.

Brent, A.C., van Erck, R.P.G., Labuschagne, C., 2007. Sustainability Cost Accounting: Part 2 – A case study to demonstrate and assess the introduced monetary procedure to evaluate the sustainability of technologies in the South African process industry. South African J. Industrial Eng., in press.

Briassoulis, H., 2001. Sustainable development and its indicators: Through a (planner's) glass darkly. J. Env. Planning and Man. 44 (3), 409-427.

Clark, W.C., Dickson, N.M., 2003. Sustainability science. Proceedings of the National Academy of Sciences of the United States of America 100 (14) 8059-8061, website: http://www.pnas.org/cgi/content/full/100/14/8059, accessed 20 December 2006.

Coles, A.-M., Peters, S., 2003. Sustainable development, global innovation and advanced technologies: The case of fuel cells. Int. J. Env. Tech. and Man. 3 (3/4), 278–289, In: 2005. Alternative Energy Sources. Fuel and Energy Abs, 46 (1), 26.

Cooney, R., 2004. The precautionary principle in biodiversity conservation and natural resource management: An issue paper for policy-makers, researchers and practitioners. IUCN Policy and Global Change Series No. 2, World Conservation Union, IUCN, Cambridge, UK.

Demaid, A., Quintas, P., 2006. Knowledge across cultures in the construction industry: Sustainability, innovation and design. Technovation 26 (5-6), 603-610.

Dunmade, I., 2002. Indicators of sustainability: Assessing the suitability of a foreign technology for a developing economy. Tech. in Soc. 24 (4), 461-471.

Engineering and Technology Management Education and Research Council (ETMERC), 2006. Main research areas. Website: http://www.etmerc.org, accessed 20 December 2006.

European Institute for Technology and Innovation Management (EITM), 2001. Our purpose and mission. Website: http://www-eitm.eng.cam.ac.uk, accessed 20 December 2006.

Fahmy, Y.M., 2005. Catalysis role for sustainable industrial development in Egypt with prospective. Technovation 25 (6), 645-655.

Geisler, E., 2002. The metrics of technology evaluation: Where we stand and where we should go from here. Int. J. Tech. Man. 24 (4), 341-374.

Gerstlberger, W., 2004. Regional innovation systems and sustainability: Selected examples of international discussion. Technovation 24 (9), 749-758.

Grieve, R.H., 2004. Appropriate technology in a globalizing world. Int. J. Tech. Man. and SD. 3 (3), 173-187.

Hamilton, W.F., 2001. The biotechnology revolution: Lessons for technology management research and practice. Int. J. Biotech. 3 (1-2), 157-167.

Hanley, N., Shogren, J., White, B., 1997. Environmental economics in theory and practice. Palgrave Macmillan, United Kingdom.

Harris, R., Khare, A., 2002. Sustainable development issues and strategies for Alberta's oil industry. Technovation 22 (9), 571-583.

Harris, S., Pritchard, C., 2004. Industrial Ecology as a learning process in business strategy. Prog. in Industrial Ecology 1 (1/2/3), 89-111.

International Association for Management of Technology (IAMOT), 2006. IAMOT Body-of-Knowledge (BoK). Website: http://www.iamot.org/bok/, accessed 20 December 2006.

International Environmental Technology Centre (IETC), 2003a. Environmentally Sound Technologies and Sustainable Development. United Nations Environment Programme, website: http://www.unep.or.jp/ietc/knowledge, accessed 20 December 2006.

International Environmental Technology Centre (IETC), 2003b Technology Transfer: The Seven “C”s for the Successful Transfer and Uptake of Environmentally Sound Technologies. Division of Technology, Industry and Economics, United Nations Environment Programme, website: http://www.unep.or.jp/ietc/knowledge, accessed 20 December 2006.

Jacob, W.F., Kwak, Y.H, 2003. In search of innovative techniques to evaluate pharmaceutical R&D projects. Technovation 23 (4), 291-296.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore III, B., O'Riordan, T., Svedin, U., 2001. Sustainability Science. Science 292 (5517), 641-642.

Khalil, T.M., Ezzat, H.A., 2005. Management of technology and responsive policies in a new economy. Int. J. Tech. Man. 32 (1-2), 88-111.

Knot, J.M.C, van den Ende, J.C.M., Vergragt, P.J., 2001. Flexibility strategies for sustainable technology development. Technovation 21 (6) 335-343.

Labuschagne, C., Brent, A.C., 2005. Sustainable Project Life Cycle Management: The need to integrate life cycles in the manufacturing sector. Int. J. Project Man. 23 (2), 159-168.

Labuschagne, C., Brent, A.C., Claasen, S.J., 2005a. Environmental and social impact considerations for sustainable project life cycle management in the process industry. Cor. Social Resp. and Env. Man. 12 (1), 38-54.

Labuschagne, C., Brent, A.C., van Erck, R.P.G., 2005b. Assessing the sustainability performances of industries. J. Cleaner Prod. 13 (4), 373-385.

Labuschagne, C., Brent, A.C., 2006. Social indicators for sustainable project and technology life cycle management in the process industry. Int. J. Life Cycle Assess. 11 (1), 3-15.

Lambert, A.J.D., Boons, F.A., 2002. Eco-industrial parks: Stimulating sustainable development in mixed industrial parks. Technovation 22 (8), 471-484.

Liao, S.-H., 2005. Technology management methodologies and applications: A literature review from 1995 to 2003. Technovation 25 (4), 381-393.

Maine, E., Probert, D., Ashby, M., 2005. Investing in new materials: a tool for technology managers. Technovation, 25 (1), 15-23.

Malairaja, C., Zawdie, G., 2004. The 'black box' syndrome in technology transfer and the challenge of innovation in developing countries: The case of international joint ventures in Malaysia. Int. J. Tech. Man. and SD. 3 (3), 233-251.

Mebratu, D., 1998. Sustainability and Sustainable Development: Historical and conceptual review. Env. Impact Assess. Rev. 18, 493-520.

Momaya, K., 2005. Technology management and competitiveness: is there any relationship? Int. J. Tech. Transfer and Commercial. 4 (4), 518.

Monaghan, P., 2003. Interdisciplinary research design. School for New Learning, DePaul University, website: http://snl.depaul.edu, accessed 20 December 2006.

Mulder, J., Brent, A.C., 2006. Selection of sustainable agriculture projects in South Africa: Case studies in the LandCare programme. J. Sustain.Agric. 28 (2), 55-84.

Murto, P., 2000. Competitive equilibrium and investments in a growing market: The choice between small- and large-scale electricity production. Annual Meeting of the Energy Economics Subprogram of the NERI, Reykholt, Iceland, website: http://www.ioes.hi.is/rammi4.htm, accessed 20 December 2006.

Phaal, R., Farrukh, C.J.P., Probert, D.R., 2006. Technology management tools: Concept, development and application. Technovation 26 (3) , 336-344.

Phaal, R., Farrukh, C.J.P., Probert, D.R. 2004. A framework for supporting the management of technological knowledge. Int. J. Tech. Man. 27 (1), 1-15.

Pilkington, A., Teichert, T., 2006. Management of Technology: Themes, concepts and relationships. Technovation 26 (3), 288-299.

Pohl, C., 2001. How to bridge between natural and social sciences? Natures Sciences Societes 9 (3), 37-46.

Portland State University, 2003. ETM study: List of current responses. Website: http://www.etm.pdx.edu/survey/results.asp, accessed 20 December 2006.

Pretorius, M.W., de Wet, G., 2000. A model for the assessment of new technology for the manufacturing enterprise. Technovation 20 (1), 3-10.

Rennings, K., Wiggering, H., 1997. Steps towards indicators of sustainable development: Linking economic and ecological concepts. Ecological Econ. 20, 25-36.

Robèrt, K.-H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P., Wackernagel, M., 2002. Strategic sustainable development: Selection, design and synergies of applied tools. J. Cleaner Prod. 10, 197-214.

Sharif, N., 1992. Technological Dimensions of International Cooperation and Sustainable Development. Tech. Forecasting and Social Change 42 (4), 367-383.

Struyf, I.L.R., 2003. Inter-organizational learning for sustained competitiveness and ecological sustainability – the case of beta-testing activities of alternative-fuel, fuel cell-driven public transport buses. Doctoral research paper, Erasmus Centre for Sustainability and Management, Erasmus University, Rotterdam, the Netherlands.

Tsoutsos, T.D., Stamboulis, Y.A., 2005. The sustainable diffusion of renewable energy technologies as an example of innovation-focused policy. Technovation 25 (7), 753-761.

United Nations Commission on Sustainable Development (UNCSD). Indicators of sustainable development: Guidelines and methodologies. 2001; website: http://www.un.org/esa/sustdev/isd.htm, accessed 20 December 2006.

University of Pretoria. Related links: Technology Management Mindmap. 2006; website: http://www.up.ac.za/engmot, accessed 20 December 2006.

Watanabe, C., Kondo, R., Nagamatsu, A., 2003. Policy options for the diffusion orbit of competitive innovations: An application of Lotka–Volterra equations to Japan's transition from analog to digital TV broadcasting. Technovation 23 (5), 437-445.

World Bank (2001). What is Sustainable Development. Website: http://www.worldbank.org/depweb/english/sd.html, accessed 20 December 2006.