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Sustainability Assessment: Assessing the Sustainability of Business Activities

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Abstract

A number of management tools exist which purport to evaluate the sustainability of a company, including life cycle assessment, environmental risk assessment, triple bottom line or global reporting and sustainability indicators. None of these, though, clearly provide a means of determining when an activity, be it manufacturing or provision of a service, is sustainable. However, they do provide the basis for sustainability assessment (SA) which determines the sustainability of activities, including processing, manufacturing, product use, provision of services and other corporate activities. Sustainability is measured as the probability of activities being able to continue without damage to the environment or society and ensuring ongoing economic feasibility. The probability is determined by evaluating the risk of damage to the environment and society over time, with full sustainability being considered to be <5% risk over 1000 years. SA provides an effective means for companies to determine the sustainability of their activities and to prioritise and modify activities to increase sustainability. It is also a valuable tool for use by engineers, planners and managers in designing and managing products, services, processes and systems for sustainability. Examples of its application to corporate activities and to manufacturing will be given.

Keywords: sustainability assessment, sustainability engineering, risk assessment, life cycle assessment

Introduction

Businesses currently have a wide range of tools which are used to measure their environmental and social performance. These include environmental risk assessment, life cycle assessment, triple bottom line or global reporting, environmental assessment, the Natural Step and sustainability indicators. Each of these tools provides a different measurement of the performance of a business or a corporation and have been used to improve products, processes, specific projects, corporate management and other activities to reduce the impact of the business and its activities on the environment. None of these tools were designed to measure the sustainability of an activity although sustainability indicators were designed to measure the progress towards sustainability. However, the tools could provide a useful basis in assessing activities for sustainability.

Environmental risk analysis is broadly defined to include risk assessment, risk characterization, risk communication, risk management, and policy relating to risk, specifically to human health and the environment, both built and natural. Threats from physical, chemical, and biological agents and from a variety of human activities as well as natural events can be considered although the focus of risk analysis is on known hazards (Louvar and Louvar, 1998). Overall, risk assessment evaluates the risk of an activity or policy but does not determine the sustainability. Santillo and Johnston (1999) argue that precautionary approaches are scientifically more robust than risk based approaches and more likely to result in sustainable activities. However, Steinhäuser (2000) pointed out that the two approaches were not incompatible and that risk based approaches could be made more robust to achieve precautionary and sustainability goals.

Life cycle assessment has been used for assessing the impact of products and processes on the environment while sustainability indicators are used to determine if the system or service can be continued over a long period of time. However, life cycle assessment (LCA) is primarily focused on identifying the environmental impacts of manufacturing activities and products, including the impact of disposal and attempts to quantify qualitative assessments. It does not determine how long the activity can be continued, environmentally, socially or economically. Therefore, although some of the methods can be used to assess the impact, to determine the sustainability of the process will require further analysis.

Triple bottom line or global reporting provides a framework for an organisation for reporting on the linked aspects of sustainability - the economic, the environmental, and the social linked elements of sustainability as they apply to an organisation. Most systems treat the three elements separately although an integrated reporting format is now being developed (Global Reporting Initiative, 2001). However, triple bottom line reporting assumes that, if all the indicators within each aspect are met by an organization, the overall organization is sustainable, although there is no evidence to substantiate this.

Environmental assessment is a tool for national or local development planning and evaluates the impact of an activity or policy on the environment. With the exception of New Zealand, most environmental assessment requirements were in place prior to any requirement for sustainability; New Zealand is the only country with an effects based legislation specifying sustainability as the fundamental practice. George (1999) evaluated environmental assessment for its use in measuring sustainability and considered it to be an effective tool on the criteria he set; however, he did not evaluate the criteria to determine if they were sufficient to measure sustainability and, did admit that his approach could readily allow an operation such as a landfill, which, in itself, may have been sustainable, but with respect to its effect on human behaviour and society, was not.

The Natural Step provides a theoretical framework for orienting public and corporate decision-making towards socioecological sustainability. Its core principles or systems conditions focus on the concept that societies are mining and releasing matter of a quantity and type that the biosphere cannot fully assimilate, and that this cannot continue indefinitely. The four conditions to reduce this are intended as a scientifically defensible, minimal representation of the requirements of sustainability which, when adhered to, will result in sustainability. However, Upham (2000) points out that TNS relies heavily on rhetoric and that the four conditions are sufficiently precautionary that few companies would be able to commit to them. Consequently, the practical application of TNS is subject to multiple interpretations.

Sustainability indicators have been devised to provide a measure of changes resulting from an activity or policy and, hench, measure the progress towards sustainability. The Bellagio Principles were drafted to provide guidelines for setting out such indicators and communities (Hardi and Zdan, 1997) and companies have been setting out such indicators as a component of their commitment to Agenda 21. However, Kelly (1998) points out that most indicators were based on a simple Driving Force – State – Response model which was too simplistic to be an effective model for a complex system. George (1999) found that indicators serve “only to indicate progress towards or away from individual aspects of sustainable development, as defined through the various components selected for inclusion in the indicator set.”

There have been attempts to undertake sustainability assessment (Culaba and Purvis, 1999, Bastianoni, 2001, AboulNaga and Elsheshtawy, 2001). However, many of these have simply extended life cycle assessment and do not seriously address sustainability, ignoring the ability of natural systems to provide sufficient energy and materials for long term operation. Moreover, economic sustainability is also usually ignored. For example, Bastianoni et al. (2001) assessed agricultural practices in Chianti, Italy, comparing different practices and determined that agricultural practices in this region were more sustainable than practices in other regions simply because the environmental impact of these practices were lower. Yet this assessment did not determine how long the practices could continue using fossil fuels and fertilisers or causing impacts on the environment. Nor did it assess the economic returns from such practices or the social factors which these practices affected.

The University of Michigan Housing Division created an environmental management system based on sustainability and applied the system to its own operation successfully (Shriberg, 2001). Life-cycle assessment, full cost accounting and indicators were used as tools within this system. However, the underlying definition of sustainability was not clear beyond “integrating environmental and social goals into all facets of decision-making.” and a clear process was not defined.

The above tools have been well researched and applied over the past 20 years. Although they do not measure sustainability themselves, it is possible that these tools can be used to measure the progress towards achieving a clearly defined goal of sustainability. One of the major stumbling blocks is a measurable definition of sustainability.

This discussion will focus on assessing the sustainability of activities, particularly products, processes, services and systems. In order to measure the sustainability of an activity, first a measurable definition of a sustainable activity needs to be clearly stated; then a clear methodology needs to be defined to determine how an activity can be measured for sustainability. The methodology needs to be sufficiently robust enough that it can measure different types of activities and be undertaken by different evaluators and provide a comparable result. Finally, some examples of how such an assessment could be applied to the construction industry will be discussed.

Defining sustainability

A measurable definition of sustainability is necessary in order to determine if an activity meets that definition. Many definitions have been proposed for the concept of sustainability, ranging from that proposed by the Brundtland Commission (1987) as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs' to 'improving the quality of human life while living within the carrying capacity of supporting ecosystems' as proposed by IUCN/UNEP/WWF (1991) in their report "Caring for the Earth". The concept of quality of life is much more nebulous than that of needs since quality of life can mean many things to many people beyond the concept of needs. Each person has a different idea of what constitutes 'quality of life'. Moreover, sustainability is not about providing luxuries to the affluent and thus improving their concept of quality of life; it is, however, about ensuring that the basic needs of people are met. The concept of 'carrying capacity' is equally nebulous as carrying capacity changes as local conditions change (drought, flooding, heat, cold) and as species' numbers fluctuate due to disease, food availability and hunting. Long term damage to the environment is, however, much more understood and, with the research into ecosystems and impact assessment, easier to determine.

Consequently, a definition that can be measured is

> *minimising the short and long term impact on the environment while meeting the needs of present and future generations.*

The time frame for short and long term impacts needs to be considered as does that of needs of present and future generations. Most companies only plan for 5 years and political planning is often even shorter. Currently, the maximum period for long term thinking is usually about 50 – 100 years, but this is insufficient when managing ecosystems which contain trees and other organisms which are over 300 years old. Although a millennium appears to be a long period of time, it must be recognised that, environmentally, this is not a long period, only 30-40 human generations. Some plants have lifespans that long or longer and a number of ecosystems can live that long (Tyrrell and Crow, 1994; Foster, Orwig and McLachlan, 1996). We are also producing wastes which will be hazardous for over 1000 years and we know our current storage of those wastes is unlikely to be contained for 1000 years. The sustainability movement arose due to the legacy of depletion and waste we are leaving future generations, not only 100 years or 4 generations ahead but 1000 years, or 30-40 generations ahead. If we are to seriously accept sustainability, then we need to be considering the effect of our activities for the long term, over the next 1000 years.

Assessing Sustainability

Rapport, Costanza and McMicheal (1998) contend that sustainability can only be determined after the fact since unseen factors may result in the early demise of the system. Certainly when considering impacts over the next 1000 years, we have little experience in managing either human affairs or the environment over such a long period. The probability of achieving sustainability, though, can be assessed by determining the probability that an activity can be sustained over a long term without damaging the environment and while meeting the needs of humanity. Thus the potential for sustainability can be determined by defining the risk of damage from an activity and the probability and length of the activity's duration without causing damage to environmental, social or economic systems. Once the major risks to sustainability are identified, they can be addressed, thus increasing the probability of sustainability.

The basic issue that must be considered when assessing an activity for sustainability is if the activity can be continued or sustained indefinitely, without damage to the fundamental global system of the environment and human social condition. If the activity uses limited resources without recycling or replacement, damages the environment or negatively affects the human social condition or the economic system then the activity cannot be continued indefinitely.

The risk of the activity negatively affecting the environment, society or economics is used to define the probability that sustainability can be achieved (SP) and is calculated as:

$$SP = 1 - R$$

where R = risk of damage for the time for the damage to occur.

For example, if the risk of an activity is 85% that damage to the environment will occur within 50 years then the sustainability probability of that activity would be SP_{50} = 15% - a 15% chance that the activity will not cause damage after 50 years. Full sustainability would be defined as SP_{1000} = 95%; a 95% chance that the activity will not cause damage over a 1000 years. Of course, the ultimate goal is SP_{∞} = 100%, which means that there is no chance of an activity damaging the environment even if it were to continue forever.

In order to assess the sustainability of a company's activities then:

a) The actions of a company over a period of time need to be identified and categorised into major activities. Thus if equipment is being purchased, the activity for which it was purchased is determined and that action is categorised under that activity. All company actions must be included in the assessment.
b) The life cycle of each activity is then determined, from cradle to grave.
c) The characteristics and quantities of all inputs and outputs of each action are then identified, together with effects on the environment over a millenium;

d) The future effects of each activity on the environment are predicted using modelling. This must include the effect on the environment as well as on human behaviour. For example, the effect of increasing landfill space is that landfilling costs decrease and companies and consumers have no incentive to reduce waste;
e) The risk of each action damaging the environment over time is determined;
f) The risk (R) with the shortest time period (T) for the activity is the risk against sustainability;
g) The Sustainable Probability of the activity then becomes $(1\text{-}R)_T$.

The activity SP is selected as the shortest time period since this indicates the period at which the activity will cause environmental damage. It should be noted though that actions that occur today but have a delayed effect, such as the estimated 50-year delay in the climate change effect of CO_2 release, are considered to have an immediate effect, particularly if there are no means taken immediately to counter the effect (for example, planting trees). However, if the cumulative effect of activities has an effect only after several years (e.g. progressive loss of habitat), then the time period would be several years.

Environmental Sustainability

For environmental sustainability, the major global issues that need to be considered can be derived from Agenda 21 (UNEP, 1994) and include:

a) Environmental and human health;
b) Resource consumption;
c) Water quality and quantity;
d) Biodiversity;
e) Climate change;
f) Land use and productivity;
g) Food production.

It is likely that local issues may also have to be addressed.

In terms of sustainability, the major concerns lie with damage to the environment. Although such damage may be due to the release of toxic materials into the environment, it may also be due to changes caused in the environment – for example the movement of material which changes the flow of a river. Certainly the removal from or addition of any material to an ecosystem will cause changes. The risk of these changes to the ecosystem can be identified using standard environmental risk methodologies.

In assessing the sustainability of resources, the loss, recycle and renewal of the resource must be considered. Resources can be classed as 1) property preserving or 2) property losing. Those in class 1 include elements, minerals etc., essentially those materials whose properties are not lost as they are used. Elements can be readily recycled, often at a cheaper cost than extraction and processing and, although they can be dispersed, ionic properties enable them to be recollected at a cost. In addition, although many metals have been mined extensively, the actual limits of deposits are still not known as production is still easily meeting demand (World Resources Institute, 1994). Although such limits may be determined within the next 500 – 1000 years, the metals that are already in use will still be available for reprocessing into new products. Although there is a risk of depleting the geologically-stored reserves, there is no risk of depletion of the elements although the cost of their recovery may increase.

Class 2, however, includes complex materials which are broken down, consumed or lose their useful property during their use. They must be replenished at the rate of consumption or will be depleted. The crash of a number of fishing stocks within the past ten years throughout the world is a good example. Other geologically-stored complex resources, such as oil and gas, are also at risk, as are radioactive materials, since the properties of these resources are depleted as they are used. The USGS has recently produced estimates of total global oil resources and, using these results, the US Energy Information Administration (2000) suggests that production will peak in 30-40 years, with the majority of resources being depleted by the end of the current century. For those resources which can be renewed within a short timeframe, an assessment of the sustainability of the consumption and renewal of such resources is necessary. For those which are not renewable, an assessment of the availability of substitutes must be considered. The risk then to future production of the resource from current management practices requires assessment.

Social Sustainability

It is likely that social risk will be the most difficult to assess since there are differing ideologies among many religions and cultures. However, Peet and Bossel (1999) identified nine basic orientors of system behaviour which are the drivers or needs of human society:

> Existence – provision of the basic biological needs of its members: food, drink, shelter, and medical care;
> Effectiveness – provision for the production and distribution of goods and services;
> Freedom of action;
> Security - provision for the maintenance of internal and external order;
> Adaptability – able to change;
> Coexistence – able to exist peacefully with other races and species;
> Reproduction - provision for the reproduction of new members and consider laws and issues related to reproduction;
> Psychological needs – provision of meaning and motivation to its members;
> Ethical reference – provision of definitions of right and wrong.

The major issues that need to be considered are derived from Agenda 21 (UNEP, 1994) and include:

a) Poverty;
b) Civil unrest;
c) Consumption patterns;
d) Demographic dynamics;
e) Human health conditions;
f) Human settlement development;
g) Incorporation of environment and development in decision-making.

Although these are not basic needs, they have been identified as the major impediments to achieving social sustainability.

Putnam (1993) found in his study of Italian regional communities to determine why some were successful, that social capital was the most significant factor. Residents were engaged by public issues, trusted one another to act fairly and obey the law and social organisations facilitated coordination and cooperation. Unsuccessful communities however, showed little social engagement, public affairs were the responsibility of politicians or the 'bosses' and strong social discipline was required. He noted that successful communities became wealthy because of the social capital and, consequently, that social capital may be a prerequisite for positive economic development and good government. Certainly a successful community has greater ability to consider the issues identified in Agenda 21 than an unsuccessful community. Since, however, social capital is a public good, it is rarely, if ever, measured by private agents. Yet it is likely to be the cornerstone of social sustainability.

The overall corporate strategy for meeting social needs will, of course, need to be taken into account. This includes employee training and support, sponsorships, community support, allowance of unions etc. It must be recognised that the external impact of the corporation on society must be evaluated, both locally and globally against the needs of people and particularly in their effect on building trust.

Economic sustainability

In terms of economic sustainability, economics should be viewed as the fuel behind sustainability, not the *raison d'etre* of sustainability. Thus, focusing on economics for its own sake entirely belies the function of society and its role within the environment. Therefore, profitability must be considered but maximum profitability is not the focus. Rather the long term sustainability of an activity needs to be considered, thus sufficient profit to ensure the ongoing operation of the activity is essential. However, while the company must be able to operate without a loss, the investment in employment and training, research and development, innovation, productivity etc. must also be considered.

Examples of SA

Of the risks associate with most activities, production of greenhouse gas emissions from combustion is likely to be the most common. According to the International Panel on Climate Control (IPCC) it is likely (66-90%) that emissions of CO_2, aerosols and other greenhouse gases are causing increased warming (Houghton et al., 2001). The IPCC also indicates that the effects of greenhouse gases persist for several centuries after release due to complexities in ocean circulations. It is likely that some effects would be positive, such as increases in minimum temperatures in cold climates, thus increasing biodiversity, food production and land use and improving human health for those regions. However, the increase of maximum temperatures in warmer climates would increase desertification, decrease biodiversity, food production and land use and negatively affect human health. In addition, ocean levels will rise, placing many island nations at risk. Overall, it is likely that small changes will be beneficial or manageable; however, a change greater than 3^oC is likely to have a negative effect, particularly if it occurs over a short time frame. Overall, for sustainability, the precautionary principle must be applied. Therefore the risk of negative effects from burning fossil fuels would be R_0 = 66-90% and the SP_0 = 10-34%; that is the potential for achieving sustainability is 10-34% over the next year. Of course, if trees are being planted sufficient to mitigate the release of CO_2 and other greenhouse gases from burning of fossil fuels and production of aluminium and concrete and other materials, this would increase the SP and attention would then focus on the pollutants emitted through combustion of fossil fuels.

Assuming that all CO_2 and other greenhouse gas emissions from construction and operation of a building are mitigated through planting of long term mixed forest, the SP of a building can be determined for other concerns. For a building that is replacing another building within a city, there is likely to be little impact on native vegetation or wildlife; this would have to be considered though for a building constructed on rural or vegetated land.

Within the construction industry, the activities include production of the materials required for construction, including timber, concrete, plaster board, steel, asphalt, aluminium etc., the energy in designing and building the edifice, the materials and energy required for maintaining the building, energy for eventual demolition and the disposal of the materials following the demolition of the building. Of the resources used in these activities, energy is probably the most limiting, as most transportation and material production is reliant on fossil fuels, which have a duration of supply of less than 50-100 years (US Geological Survey, 2000), depending on the fuel. In contrast, production and use of materials such as concrete contribute to climate change, affects environmental and human health through emissions and, depending on the operation and the material, can affect land use, soil quality and water quality. For concrete, the raw materials include limestone, shells or chalk, and shale, clay, sand, or iron ore, all of which are in great abundance globally, although they may be locally scarce. The impact of mining, processing and shipping the raw materials would need to be considered. In addition, concrete can be recycled for some purposes and is relatively inert. The impact of timber in construction, however, depends on the source, milling, the preservative process, shipping and recycling. Thus for construction materials, production practices, energy consumption, emissions, effluents and recycling are all of concern.

The impact of the construction on human needs must also be considered. Construction of a building on a sacred site may result in clashes between cultures or in civil unrest while construction of a home for older citizens will provide shelter and care for those unable to manage on their own. Training and employment of local workers will provide a benefit to the community, assuming that employees are given fair wages, provided with safety equipment and training and treated equitably and fairly. In addition, the effect of construction on local businesses must also be considered; if materials are being obtained locally, then the construction will have a major benefit while materials obtained from other localities when they are available locally will have a detrimental effect.

Finally the life cycle cost of the building and its amenities needs to be assessed. The use of solar heating, rain water collection and high insulation needs to be considered for the long term effects on building cost as will the duration of the building materials and the quality of the construction. Capitalisation requirements to construct the building and ongoing maintenance costs of the building must be clearly determined.

Future Requirements

The modelling requirements to predict the risk are being developed as the science of risk assessment develops. Issues that need to be resolved include the assigning of risk factors to activities and acceptable tolerances as well as the effect of background or low levels of pollutants on human and environmental health (Eduljee, 2000). The assessment of risk over time also needs to be better developed (Karman, 2000). In addition further work on the development of models which calculate the environmental, social and economic risk of activities is needed and is currently being undertaken as a continuation of this research.

Although SA uses risk analyses as a basis, it differs from standard risk assessment in a number of ways – it combines environmental, social and economic risk with life cycle analysis over the long term to determine the descending limiting factors for sustainable continuation of an activity, rather than just assessing specific environmental risks. Moreover, SA provides an effective goal and a clear method to defining the sustainability of an activity. It also takes a more precautionary approach rather than a risk based approach towards management. Finally it can be used for any activity, including production and use of products, processes, services, or systems.

Conclusions

A sustainable system can be defined as one which persists; however, only the probability of sustainability can be assessed since sustainability can only be determined after the fact. The risk of activities detrimentally affecting a system can then be determined, together with the time until such damage would occur. The probability of sustainability (SP) then becomes 1-risk of damage for the time for the damage to occur. Full sustainability would be defined as SP_{1000} = 95%; a 95% chance that the activity will not cause damage over a 1000 years. Of course, the ultimate goal is SP_{∞} = 100%, which means that there is no chance of an activity damaging the environment even if it were to continue forever.

Sustainability should initially focus on major concerns – for the environment this would include environmental and human health, resource consumption, water quality and quantity, biodiversity, climate change, land use and productivity and food production. For social sustainability the major concerns are poverty, civil unrest, consumption patterns, demographic dynamics, human health conditions, human settlement development and incorporation of environment and development in decision-making.

Finally for economic sustainability, economics should be viewed as the fuel behind sustainability. Therefore, the long term sustainability of an activity needs to be considered, thus sufficient profit to ensure the ongoing operation of the activity is essential. However, while the company must be able to operate without a loss, the investment in employment and training, research and development, innovation, productivity etc. must also be considered.

SA enables an effective comparison to be made between systems and services, sets priorities on the outcomes and should be more readily understood by the public, thus allowing companies to measure the sustainability of their service or system and better incorporate sustainable services or systems into their operation. Further research is required to fully develop models which will undertake sustainability assessment and to further develop risk assessment methodologies.

References

AboulNaga, M.M. and Y. H. Elsheshtawy, 2001. Environmental sustainability assessment of buildings in hot climates: the case of the UAE *Renewable Energy* 24 (2001) 553–563.

Bastianoni, S., N. Marchettini, M. Panzieri, , E. Tiezzi, 2001. Sustainability assessment of a farm in the Chianti area (Italy). *Journal of Cleaner Production* 9 (2001) 365–373.

Brundtland Commission, 1987. *Our Common Future*. Oxford University Press, Oxford, UK.

Culaba, A.B., M.R.I. Purvis, 1999. A methodology for the life cycle and sustainability analysis of manufacturing processes. *Journal of Cleaner Production* 7 (1999) 435–445

Eduljee, G.H., 2000. Trends in risk assessment and risk management. *The Science of the Total Environment* 249:13-23.

Foster, D.R., D.A. Orwig and J.S. McLachlan, 1996. Ecological and conservation insights from reconstructive studies of temperate old-growth forests. *Trends in Ecology and Evolution* 11(10):419-424.

George, C., 1999. Testing for Sustainable Development Through Environmental Assessment. *Environmental Impact Assessment Review* 19:175–200.

Global Reporting Initiative, 2000. *Sustainability Reporting Guidelines on Economic, Environmental, and Social Performance*. Global Reporting Initiative, www.globalreporting.org.

Hardi, P. and Zdan, T. (1997). *Assessing Sustainable Development: Principles in Practice*. International Institute for Sustainable Development, Winnepeg, Canada.

Houghton et al., 2001. *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, UK.

IUCN/UNEP/WWF. 1991. *Caring for the Earth: A Strategy for Sustainable Living.* Gland, Switzerland.

Karman, C.C., 2000. The Role of Time in Environmental Risk Assessment. *Spill Science & Technology Bulletin*, Vol. 6, No. 2, pp. 159-164, 2000

Kelly, K.L., 1998. A systems approach to identifying decisive information for sustainable development. *European Journal of Operational Research* 109(1998): 452 – 464.

Louvar, J.F. and B.D. Louvar, 1998. *Health and Environmental Risk Analysis: Fundamentals with Applications*. Prentice Hall, New Jersey.

Peet, J. and H. Bossel, 1999. Ethics as the grounding of a new paradigm of ecological economics for community. *ANZSEE Conference*, Brisbane, Australia, 5-7 July, 1999.

Putnam, R., 1993. *Making democracy work : civic traditions in modern Italy*. Princeton University Press, Princeton, New Jersey pp.258.

Rapport, D.J., R. Costanya and A.J. McMicheal, 1998. Assessing Ecosystem Health. *Trends in Ecology and Evolution* 13(19)397-401.

Santillo D., and P. Johnston, 1999. Is There a Role for Risk Assessment within Precautionary Legislation? *Human and Ecological Risk Assessment* 5(5):923-932.

Shriberg, M., 2002. Toward sustainable management: the University of Michigan Housing Division's approach. *Journal of Cleaner Production* 10(1): 41-45.

Steinhäuser, K.G., 2001. Environmental risks of chemicals and genetically modified organisms: a comparison. Part II: Sustainability and precaution in risk assessment and risk management. *Environmental Science and Pollution Research International* 8(3):222-226.

Tyrrell, L. E. and T.R. Crow, 1994. Structural characteristics of old-growth hemlock-hardwood forests in relation to age. *Ecology* 75(2): 370-386

Upham, P., 2000. An assessment of The Natural Step theory of sustainability. *Journal of Cleaner Production* 8 (2000) 445–454.

UNEP, 1994. *Agenda 21 – Introduction*. UNEP, available at http://www.unep.org/Documents/Default.asp?DocumentID=52&ArticleID=50

US Energy Information Administration, 2000. *Long Term World Oil Supply* (A Resource Base/Production Path Analysis) 07/28/2000. Department of Energy, presentation available at http://www.eia.doe.gov/pub/oil_gas/petroleum/Presentations/2000/long_term_supply/index.htm

US Geological Survey, 2000. *World Petroleum Assessment, 2000*. US Geological Survey, http://greenwood.cr.usgs.gov/energy/WorldEnergy/DDS-60/

World Resources Institute. 1994. *World resources 1994-95*. New York: Oxford University Press.