UNIVERSITY OF SOUTHERN QUEENSLAND

Sustainability Philosophy in Engineering Context Review and Discussion

A Dissertation submitted by

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Abstract

Subsequent to the Rio Earth Summit both the engineering industry and the profession alike recognized the need for shifting towards sustainable practices. Similarly literature is mushrooming with sustainability definitions, themes and descriptions in many complex shapes and sizes, thus, presenting an immense diversity of opinion. This research defines the concept and principles of sustainability from an engineering perspective. It also addresses how sustainability philosophy or culture in engineering may one day drive net positive development.

In recent times going "green" has been the focus of governmental agencies, non-governmental organizations, private sector and society at large with a modest universality between these efforts. By way of example the overabundance of sustainability definitions and assessment tools found in literature, poses a unique set of challenges: first and foremost differing values describing how ideal criteria and indicators in sustainability assessment "should be". The surplus of definitions causes perplexity from an operational engineering perspective. This research probed sustainability operational issues experienced by engineers in the course of a series of consultative interviews with experts to account for generic criteria and indicators used in engineering sustainability assessment. This research presents a synopsis of these expert interviews. Furthermore, it reviewed and critiqued existing mechanisms, rating schemes and assessment methods frequently used by the engineering profession, in order to examine current practices purporting to enable or facilitate sustainability in engineering practice.

The study makes a contribution to sustainability science in the sense that it illustrates the concept diagrams of social, economic, environmental, technology and time criteria based on results from expert interviews. It also highlights the limitation of the rampant practice of minimizing negative impacts on the environment and society.

The research will benefit members of the engineering profession by providing them with a background on the development of sustainability within engineering, thus allowing them to make informed sustainability decisions. It is intended to outline non-specific relations between sustainability indicators and criteria for any given engineering project despite the definitional ambiguities indicators and criteria displayed.

Finally scale is important for defining sustainability approach to measurement and the outcomes in decision-making, since the majority of environmental and economic issues cut across several scales. The thesis argues for a transdisciplinary approach to achieve sustainability in engineering and sets out a typology of contexts in which this research finding could be applied and developed further.

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Certification of Dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged

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Scholarly Publications and Events
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The author has **published** the following:

1. Hasna A.M, Thorpe D, (2005), Sustainable Resource Management of engineering technologies-towards an assessment framework" proceedings of the 9th international Conference on Environmental Science and Technology , Rhodes Island , Greece , 1-3 September.
2. Hasna A.M, (2007), Dimensions of Sustainability, *Journal of Engineering for Sustainable Development: Energy, Environment*, and Health, Volume 2: Number 1, 2007, pages 47-57.
3. Hasna A.M.(2007),The engineering design process with sustainability, Proceedings of Engineering Sustainability SSEE2007, the international conference of the Society for Sustainability and Environmental Engineering, Engineers Australia, 31 October - 2 November, Perth, Western Australia
4. Hasna A.M., (2007), Sustainability and Engineering Philosophy: The Paradigm, *The International Journal of Environmental, Cultural, Economic & Social Sustainability*, Volume 3, Issue 4, pp.107-114.
5. Hasna A. M., (2008), Sustainability in Engineering Design, *The International Journal of Environmental, Cultural, Economic and Social Sustainability*, Volume 4, Issue 1, pp.69-88.
6. Hasna, AM (2009), 'A Review of Sustainability Assessment Methods in Engineering', *the International Journal of Environmental, Cultural, Economic and Social Sustainability*, vol. 5, (volume and page numbers to be advised)
7. Hasna, AM (2009), 'Contemporary Society, Technology and Sustainability', *The International Journal of Technology, Knowledge and Society*, Volume 5, (volume and page numbers to be advised)
8. Hasna, AM (2009), 'Climate Change and technology on the road to Sustainability' in proceedings of International Conference on Energy, Environment, Sustainable Development" Paris, France, June 24-26, 2009.

The author has **presented** in the following conferences,

1. 9th International Conference on Environmental Science and Technology, Rhodes Island, Greece, 1-3 September 2005.
2. *SSEE2007 Engineering Sustainability*, the international conference of the Society for Sustainability and Environmental Engineering**,** Engineers Australia, 31 October - 2 November 2007, Perth, Western Australia.

3. Panel discussion: *"Engineering skills for a sustainable world – what can PBL do?* "Research Symposium on PBL in Engineering Education, Frederik Bajers Vej 7 A, Aalborg University, Denmark, Monday, 30 June - Tuesday, 01 July 2008.

4. EESD 2009: "Climate Change and technology on the road to Sustainability", "*International Conference on Energy, Environment, Sustainable Development*" Paris, France, June 24-26, 2009.

5. "Engineering ethics and sustainability" 8th Global Conference Environmental Justice and Global Citizenship to be held from Friday 10th July -Sunday 12th July 2009 at Mansfield College, Oxford, United Kingdom.

The author was on the **editorial board** of the following Journals,

1. Associate Editor, *the International Journal of Environmental, Cultural, Economic and Social Sustainability*, Volume 3, Common ground publishing 2007.

2. Referee, Engineering Sustainability, *Proceedings of the Institution of Civil Engineers*, United Kingdom, Thomas Telford publishing ,2008.

3. Associate Editor, volumes 1 and 5, *The International Journal of Knowledge, Culture and Change Management*, 2008.

4. Member of the Technical Programme Committee for IEEE International Conference on Sustainable Energy Technologies, ICSET, 24-27 Nov *2008* - SMU *Conference* Center, Singapore.

The author has **participated** in the following conferences,

1. Second International Conference on Environmental, Cultural, Economic and Social Sustainability, East-West Centre, Hawai'i, in February 2005.
2. Third International Conference on Environmental, Cultural, Economic and Social Sustainability, Senate House at the Chepauk Campus of the University of Madras, Chennai, India, 2007.
3. Fourth International Conference on Environmental, Cultural, Economic and Social Sustainability, Universiti Malaysia Terengganu, Kuala Terengganu, Malaysia, 2008.
4. Fifth International Conference on Environmental, Cultural, Economic and Social Sustainability, University of Technology, Mauritius, 5-7 January, 2009.

Refereed International Conferences (Summary)

4 conference papers

1 conference poster

Refereed Journal Articles (Summary)

Five papers

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Abbreviations & Acronyms

ICT: Information and Communications Technology, electronic, digital media, data processing, telecommunications and the Internet.

Information society: modern forms of society and economic activity heavily dependent on the exploitation of ICT

Intrinsic value: An attitude or ethical precept that affirms the worth and significance of other beings regardless of specific human preferences, interests and aversions.

MCDA: Multiple criteria decision analysis, methods of evaluation of resource management options according to a range of criteria considered

Natural capital: Any element or system of the physical world which, directly or in combination with produced economic goods, services of value to society. Open system: an entity, differentiated from its environment, is dependent on interactions between system and environment.

Pollution: Material or energy flow, usually but not always 'by-products' of economic production and consumption activity.

Pressure-State-Response: A framework of analysis that (1) quantifies pressures of human activities of production and consumption on the environment (e.g. water extraction, fish catch, nitrate or toxic effluent emissions) (2) describes the state of the environment and observable changes in state (e.g., algae growth in lakes); and (3) the responses proposed or implemented by society (e.g., water purification stations, changed production technologies).

Sustainability indicator: An index or aggregate of information allowing an assessment of the extent to which economic activity is, or is not, compatible with goals of long-term viability/durability at a defined geographic, ecological or statistical scale.

Utopia: A (non-existing) society, described abstractly or in specific parable form, that is conceived as incarnating ideals of justice, human freedoms, cultural achievement, environmental quality, etc.

Ecocentrism: dynamic, interrelationship between all animate (human and non-human) and inanimate objects.

Green Politics: political movement in which environmental issues are of primary concern.

Framework is a construct that allows the interrogation of a system in terms of risk, cost, benefit and impact.

Industrial Ecology: is the study of the relationships of industry and their surroundings, habits and modes of life.

Model: is defined as the representation of a system include materials flux analysis and industrial ecology. Life cycle assessment is considered to be both a model and a framework.

Chapter 1. Introduction

1.0 Title of the thesis

Sustainability philosophy in the engineering context: review and discussion

1.1 Foundation for the research

> "Literature reveals definitions, themes and descriptions of sustainability in many complex shapes and sizes, ranging from strategy, framework, phrases, concepts, indexes, indictors, weak, strong, externality, internality and criterion" (Hasna, 2007b; Hasna, 2009f),

hence, presenting an immense diversity of opinion, with confusion to its literal implementation. "Sustainability" as a function of transdisciplinary variables, are underlined by three common themes: social, economic and ecological, also known as the bottom triple line. This raises more questions than answers: what is sustainability in Engineering? is it a utopian state or pseudo ideal process? is it a strategy? where do the complex issues of sustainability leave engineers? The objective of this thesis is to define the bounds of sustainability and to investigate its dimensions in order to form a contextual analysis of sustainability in engineering.

Current global environmental concerns, mainly climate change and global warming, present many problems such as inadequate food supply and energy shortages, i.e. the nuclear power generation debate. On the other hand, the decline of the Australian chemical and manufacturing industries and the shift in manufacturing to offshore countries, mainly southeast Asian developing countries (in particular India and China) has altered the distribution of wealth from traditional western developed countries to developing countries. The abovementioned issues are part of the sustainability challenges with which engineers in Australia and abroad will inevitably engage during their professional practice which also raises questions concerning the ground rules relating to engineers' accountability and their contribution to society. Are engineers motivated by profit margins, technical advancement or upholding sustainability in their work ethics? Hence, it is worth wondering whether the world is on course for further dramatic social and economic change and whether such changes, as they take place, can be steered to benefit all of human kind i.e. sustainability and growth.

On a local scale, understanding the wider international challenges facing Australian society as a whole is part of the engineering profession. Technology-driven knowledge society and knowledge economy have become common terms in our twenty-first century vocabulary, whilst globalization has deepened the economical interdependence of countries and simultaneously caused a borderless mega-competition (Hasna, 2009e). The FIDIC (2002) International Federation of Consulting Engineers states that engineers are uniquely positioned to provide leadership in implementing sustainable development. Due to their knowledge and skills and the central role they play in the development of society, engineers have a tremendous responsibility in the implementation of sustainable development. In addition, the World Federation of Engineering Organisations (WFEO, 1997), states that professional engineers provide innovative, technically-excellent and cost effective solutions to society's problems and are largely responsible for the high quality of life enjoyed by the world's developed countries. To establish a discussion on sustainability in engineering one needs to ask how engineers can contribute towards sustainability, for example, by helping the victims of the Asian tsunami, addressing the problems caused by the Australian drought, tackling the extreme poverty that so many fellow humans face daily in our region such as East Timor, the Solomon islands, the Maldives and Malawi, and the disappearing islands. These are some of the issues that the engineering profession is likely to encounter. Miller et al. (1998) asked whether humanity has the social and ecological capacity to continue to advance and invent new tools, new products and new ways of organising life. Furthermore, how can we deal with the concepts of preservation versus change, conservatism versus dynamism and incrementalism versus radicalism? These are the dividing lines of the sustainability debate as we move further into not only a new century but a new millennium. Figure 1-1 depicts the interaction and relationships that exist between government, industry and the public.

- What are the costs and the risks for the environment?
- What does it mean for society's traditions?
- Who will oversee sustainability? Governments or global institutions?

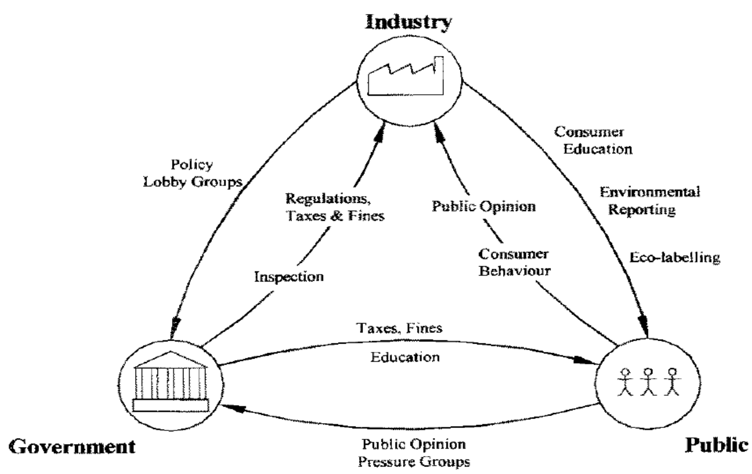

Figure 1-1:Public government & industry on environmental issues(Young, 1997)

> "The role of government is to legislate for the public good, therefore, although governments aim to foster economic growth, it must also ensure that workers, the general public and the natural environment are adequately protected. As a result of the many accidents and disasters which have occurred since the industrial revolution, public attention has become much more focused on environmental issues. Industries that came under initial scrutiny were those in the chemical processing and heavy industry sectors; however, environmental issues are now a matter of concern for all" (Young et al., 1997).

1.1.0 Industrial Ecology

Industrial ecology seeks to optimise the total industrial cycle from virgin material to finished material, from component to product and to ultimate disposal. Factors to optimise include resources, energy and capital (Graedel, 1994). The basic principle of industrial ecology was recognised some 500 years ago (Young, 1997) by Leonardo Da Vinci when he penned these words:

> "Although human genius through various inventions, makes instruments corresponding the same ends, it will never discover an invention more beautiful, nor more ready, nor more economical than does nature, because in her inventions nothing is lacking and nothing is superfluous"(Da Vinci).

The outlook and response of industry to mounting environmental pressures is summarised in

Table 1-1. This response is typical of the more progressive organisations; significant time lags are noticeable in the responses of individual companies and between industries in different countries. As industries progress from Stage I to Stage III, traditional practices must be set aside and a new paradigm adopted (Tipnis, 1993, 1994).. Similarly, with only 6 years to achieve Goal 7–"Ensure environmental sustainability" of the Millennium Development Goals (MDGs), what is the position of the engineering profession to curb public concerns i.e. global warming, climate change?

	STAGE I	STAGE II	STAGE lll
	Pre 1970s	**1970s-80s**	**1990s**
General Approach	Reactive	Compliant	Proactive
Environmental Awareness	Very limited	Limited to particular manager or department	Heightened environmental awareness in all sectors and levels of the organisation
Management Controls	Remediation	Inspection	Environmental audits
Pollution & Waste	Waste not an issue	'End of pipe' controls	Process innovation. Life cycle approach
Legislative Controls	Few regulations	Controls on emissions and waste	Integrated pollution control. Product take-back legislation

Table 1-1: Industrial response to environmental issues (Young, 1997)

1.2 Problem statement

> "The 18th century rise of the British Empire was fuelled by the Industrial Revolution, which was, in turn powered and to some degree symbolized by the heavy use of coal. Modern Germany's late-19th-century industrial expansion and its subsequent imperial aspirations were likewise supplied and characterized by massive coal consumption. The 20th century has been labelled "the age of oil". At the close of the 20th century, however, a new energy paradigm, forged by technological advances, resources and environmental constraints, and socioeconomic demands had begun to emerge" (Flavin and Dunn, 1999).

Essentially, the successful introduction of inventions into society resulted in an increase in the prosperity of western societies during the 20th century; hence technological developments and innovation played a key role in the growth of western economies (Vollenbroek, 2002). Clearly engineers and the engineering profession contributed to economic growth and in turn, the consumption of natural resources rendered the issue of sustainability an engineering issue. Hence, the "age of oil" has laid the foundation for unprecedented economic growth. While humanity has an unprecedented opportunity to succour, innovation is a key driving force for sustainability. The past decade has also seen many technological innovations in energy efficiencies, and despite the paradox of innovation and regulation (since the former is concerned with re-writing the rules and replacing the incumbent products and processes specified by the latter), both innovation and regulation are required to move industry toward a more sustainable future (Dewick and Miozzo, 2002).

> "Whether the focus is technology, the economy, or society at large, it is widely accepted that technology will have profound effects on natural resources" (Hasna, 2009f)

For instance, the digital society implies growing reliance on electricity to support 21st-century socioeconomic development, a digital society implies a growing a primary dependence on electricity and consequently networked ICTs, with more people using the internet, cell phones, digital video, digital music, and PCs etc. however there is little agreement on what this implies for the use of electricity (Bare, 2002; Yoo, 2006) as history shows that this will result in a heavier reliance on natural resources. Similarly, there are many excellent technologies developed to remedy society's demands on our natural resources, but the question raised for engineers is how to distinguish between sustainable and unsustainable practices? The inter-disciplinary nature of this topic will require more than one discipline to answer the research questions, with the main theme being applications of sustainability in engineering. The United Nations proclaimed January 2005 as the launch of the Decade of "Education for Sustainable Development".

> "Without a doubt, it can be said that engineers and engineering education are essential for bringing about sustainability, including the development and implementation of sustainable technologies and sustainable system innovations. This requires integrating sustainability thoroughly in engineering" (Quist et al., 2006).

1.2.0 National significance

According to Chisholm (2003) Society is becoming increasingly reliant on engineering and technology. The challenging landscape for Australian society in the early 21st century includes dealing with a changing climate, in particular the drought and fresh water shortages, an aging population, changing demographics and a digital and ICT dependent society, all of which assume an increasing importance on science and technology since the advancement of engineering and technology is seen as a prerequisite to successful economical growth. For example, the terms of reference of the Prime Minister's council (Howard, 2004) stated that one objective was to enhance awareness in the community of the importance of science, technology and engineering for Australia's economic and social development. The Australian Federal Government announced the Prime Minister's National Research Priorities on 5 December 2002 (Howard, 2002-

2003) which consisted of four research priorities and their associated priority goals:

- an environmentally sustainable Australia;
- promoting and maintaining good health;
- frontier technologies for building and transforming Australian industries;
- safeguarding Australia.

In view of the Australian government's top four research priorities, it is vital to revisit the environmental awareness programs that drove change in the early twentieth century, which have now crested. The national and global economic challenges presented influence the practice of sustainability management towards environmental affairs. Hence, the balance between engineering practice and sustainability knowledge is ever more important.

1.2.1 The research problem

The growing world population would not be a problem if there were unlimited land, unlimited water and unlimited resources. The implication of a world without sustainability is evident in global political concerns, highlighted by the United Nations climate change conference in Copenhagen (COP 15). While it is clear that environmental problems thwarting sustainable development emanate mostly from over-consumption by the rich and under-consumption by the poor. According to (Boehmer-Christiansen, 2002) Tony Blair, UK Prime Minister, (2001) addressed Chatham House:

> "You don't have to be an expert to realise that sustainable development is going to become the greatest challenge we face this century".

Whilst the number one sustainability challenge is to mitigate climate change, this thesis investigates the engineering contributions to the solution to the number one global challenge "climate change". The veracity of this may be judged from the following statement that underscored deliberations at the Johannesburg Summit of 2002:

> "In the ten years since Rio 1992 the international community has spent enormous amounts of money on environmental research; a veritable avalanche of books, papers and reports have been published; and armies of environmental bureaucrats have been appointed. Yet, the world of 2002 is much less sustainable than the world of 1992. Why?"

One of the reasons we propose as the engineering and science community remain on the sidelines observing the development of sustainability science take place with little involvement. Most of the discussions around the theme of sustainability from an engineering point view have a common platform but lack a universal definition of applied sustainability. There are a variety of definitions which take their form from the degree to which the concept is seen. It is important to have a working definition of sustainability from a multidisciplinary prospective. A single definition would not achieve comprehensiveness because sustainability is both simple and complex, thus it should be considered within a spectrum of definitions. However, defining sustainability must also be accompanied by an investigation of philosophy and engineering. by understanding the scope of sustainability definitions the engineering community will therefore be able to develop a unique and universal operational definition of sustainability to be applied in respective disciplines.

The purpose of this thesis is to emphasize the commonly-used sustainability definitions in literature as it reveals

> "definitions, themes, narratives and descriptions of sustainability in many complex shapes and sizes, some ranging from strategy, framework, phrases, concepts, indexes, indictors, weaknesses, strength, externality, internality and criterion, For an engineer, this presents an immense diversity of opinion, often leading to confusion as to how an engineer applies sustainability and furthermore, how it is put into practice. In this research, more questions are raised than answered. In this early stage, one would have to wonder and ask exactly what is sustainability - a utopian state or pseudo ideal process Is it a strategy? Where do the complex issues of sustainability leave engineers? With the prevalence of vicarious liability and its associated legality, will an engineer be liable for failing to design for sustainability?" (Hasna, 2009f)

1.2.2 Purpose of the study

> "The engineering profession is engaged beyond building structures, shaping tools, or the hardware curtain; professionally, engineers are engaged daily in decisions that influence the sustainability of humanity" (Hasna, 2008c).

The research investigates sustainability in engineering through other disciplines such as environmental sciences, management, philosophy, social and political sciences. It endeavours to present these different interpretations into a coordinated, coherent unit of knowledge applicable to engineers from an engineering perspective. The arising need for this research stems from my current work and exposure to various facets of the engineering industry in Australia. The main thought which assisted germination of this research was looming from the perspective of

> "What is sustainability in engineering? Does it include what happens beyond my immediate workplace? How does one "think through" the downstream effects of engineering, including its consequences to our society and its culture, while toying with the influence of technological determinism?; and how do engineers interact with society and what responsibilities do they hold towards it? After examining the foundations of design, the engineering lifecycle and the critical importance of usability, the question is often asked by engineers, "have we done enough in our work place to prevent pollution etc.." (Hasna, 2009f)

1.3 Perceived contribution to knowledge

It is clear that the world is not in need of another fanciful study of the definitions of sustainability and Sustainable development characteristics or their virtues; however this study will contribute to understanding engineer's cognition of sustainability by reviewing sustainability definitions, assessment tools, the connection between engineering and sustainability, its role in engineering design, its philosophy and conceptualisation. This thesis aims to contribute to the theory-building to focus on developing a unique and universal operational definition of Sustainability in Engineering, through exploration of expert perceptions of sustainability in the engineering industry. Such a definition does not exist even today, and this is generally acknowledged be the nemesis of Sustainable Development.

Traditionally, an environmental impact assessment was an end-of-pipe exterior informational footstep in the design process. In this thesis, I argue that sustainability assessment processes are an internal integral part of the engineering process, underpinning the operational meaning of sustainability and its application. Another central issue for engineers in the context of sustainable practices in engineering would be the plethora of measurement tools. A number of notable works had critiqued the limitations of current practices purporting to enable or facilitate sustainability in engineering practice. Primarily Hurley et al. (2008) articulated limitations of tools use to include the following;

(a) Lack of available data; "even using assumed data, the process is too time consuming to fit into ordinary work schedules"

(b) Public engagement "for evaluation of social criteria is difficult without incentives, funding and training".

(c) Criteria weighting is subjective

(d) Vague criteria definitions and sometimes overlapping.

(e) Criteria evaluations focus on negative rather than positive aspects

(f) Decisions are made based on what users think should denote importance, not what they think actually does

(g) Overtly quantitative

1.3.0 The aim of the research

In light of the growing body of knowledge on sustainability, the aim of this research is twofold: firstly, to establish a sustainability discussion in engineering and secondly, to integrate sustainability thinking into regular engineering proposals and intent, therefore presenting an operational meaning and application in a simple, practical, and objective manner, capable of being transferred across engineering projects in a rapidly changing engineering industry.

1.3.1 The objective of the research

To realize this aim, I maintain that sustainability assessment in engineering ought to be an integrated proactive process conducted within the proposal development stage. The aim will be achieved through defining the bounds of sustainability and its dimensions in order to form a methodology to quantify considerations as an inherent and inseparable part of the engineering design process.

Objective 1: To understand the current practices and definitions of sustainability that apply to engineering.

Objective 2: To define the bounds of sustainability assessments and to investigate its dimensions in order to form a methodology to quantify it.

Objective 3: To understand the philosophy of sustainability and engineering.

Objective 4: To evaluate the needs of the engineering community by gauging their opinions and their perceived requirements for sustainability.

1.3.2 Methodology

The universal objective is to define

> "the bounds of sustainability and to investigate its dimensions in order to form a sustainability discussion in an engineering context" (Hasna, 2009f)

To meet these objectives, the following key questions will be addressed in this thesis as listed below. Further explanations are illustrated in Figure 1-2.

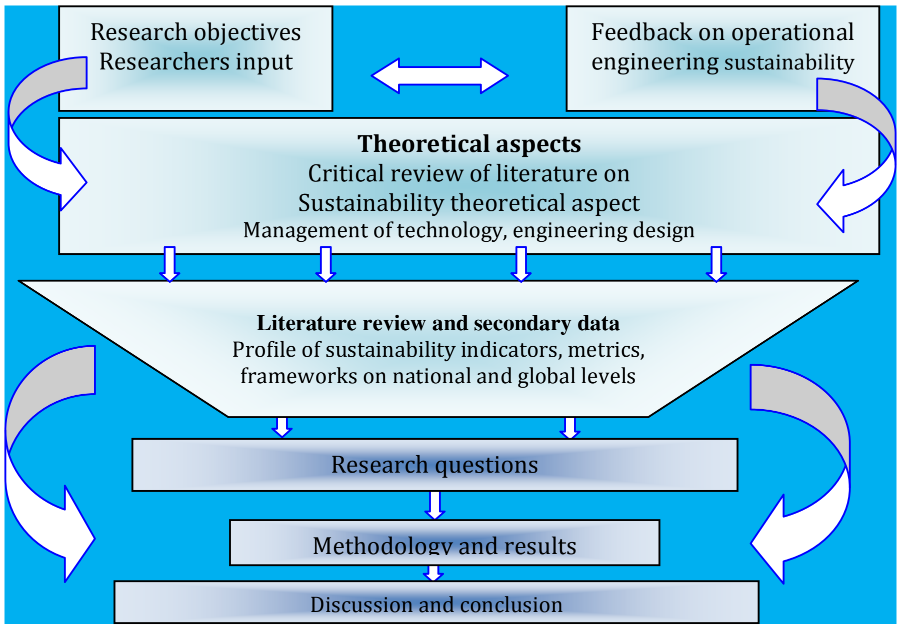

Figure 1-2: The research process of the thesis.

1.4 Research questions

Table 1-3 presents a mapping of the research objectives against the thesis chapters. A detailed description of how each functional requirement is addressed is discussed in Section 1.4.0. Based on the answers to the research questions in Table 1-3, this thesis aims to ascertain whether the research findings enhance the advancement of sustainability discussions in engineering and what policy recommendations can be given for fostering sustainable engineering practices to embed sustainability in an engineering context.

1.4.0 Critical success factors

While the literature generally promotes sustainability, quantifying a standard metric on the operational level appeared to be limited in scope. Sustainability application in engineering depends on several critical success factors [CSF], among them the availability and accessibility of relevant, accurate, complete and timely information to engineers, integration, interconnectivity between policy and users, an effective balance of privacy and anonymity of information and information-sharing needs. The critical success factors summarised in Table 1-2 in matrix format present four key issues as being critical: policy, market, information and culture (Gezinus and Williams,1997; Huovila,1999; Mazmanian and Kraft,1999;Johansson,2002; Altham,2003; Altham,2007). The policy column in Table 1-2 relates interoperability, which has been defined by skinner (2004) as a key strategy for the achievement of sustainability.

> "as the ability of systems to provide services to and accept services from other systems and to use the services so exchanged to enable them to operate effectively together (ISOTC204-N271 quoted in(McQueen and McQueen, 1999)" "The ability of two or more systems or components to exchange information and to use the information that has been exchanged (IEEE, 1990)"

			CSF			
			policy	market	information	cultural
Gap identification	Barriers	KPI	Measurement	Cost	Integrated policy institutions	desire to protect the environment
		Assessment	Inter-operability	Data processing	Willingness to share	Involvement of entire workforce
		Organisational	Tax legislation	benchmarking	Willingness to accept assistance	knowledge of sustainability regulations
	Drivers	Cost savings	Environmental accounting	Subsidies	economic benefits	Profit-driven before people
		Risk management	Enforce	improve efficiency		sustainability risks
	Tools	Action plan	Technical identification	sustainability production	Interoperability	sustainability assessment

Table 1-2 Critical success factors

From these mentioned definitions sustainability in engineering would be viewed to operate in synergy with others. Furthermore, policy implications of sustainability are becoming increasingly important in light of the current uncertainties its absence presents, equally so, given that sustainability costs are often allocated to overheads and not to those production processes or products that create these costs. This reduces the incentive to implement sustainability programs in industry. Alternatively, businesses that purchase their natural resources (energy, water and materials) at subsidized prices or pay minimal waste disposal charges are not forced to internalize total environmental costs. In either case, industry will not be able to identify or achieve significant economic benefits. Consequently, economic benefits fail as a driver for improving eco-efficiency (Altham, 2003) and subsequently, sustainability. These barriers and inappropriate industry cultures are essential for the successful rollout of sustainability metrics. For example, research on the cost of energy waste generation in the UK identified that the average total cost of waste generation was 25 times that estimated by management (Phillips et al., 1999).

Theoretical aspects of sustainability perception in engineering

Chapter 1
What is the state of sustainability in engineering?

- Is it a utopian state or a pseudo ideal process?
- Is it a strategy? Is it real or an illusion? Can sustainability, as process, be measured?
- What are the key indicators and criteria?
- What are its characteristics and challenges?

Literature review and secondary data

Chapter 2, 3and 4
What are the strengths and weaknesses of current sustainability definitions?
What level of sustainability assessment exists among engineering systems?
What is the state of sustainability capabilities in engineering?

Chapter 5 and 6
How do we improve the design processes to include sustainability?

- Where do these complex issues leave engineers and designers?
- How would engineers apply sustainability to preliminary designs?
- How strongly are sustainability values embedded into engineering?
- To what extent do criteria satisfy the sustainability appraisal?
- Identifying engineering criteria for sustainability indicators to be incorporated into the engineering decision-making process.

What is the engineering perspective on applied sustainability, what are its most important attributes and how do we try to improve it?
Identify sub criteria - indicators in literature, in order to gauge sustainability in engineering

Identify essential indicators or criteria deemed as important to the concept of sustainability in the engineering profession (projects or organisations)

Chapter 7 and 8
(1) What is the perception of sustainability in engineering? What are its characteristics or attributes?
(2) Can sustainability, as a process, be measured? What are the key indicators and criteria? What are its characteristics and challenges? What tangible information and contextual factors affect decision makers when making sustainability decisions and how do these affect decision outcomes? How do we improve the design processes to include sustainability? Where do these complex issues leave engineers and designers? How would engineers apply sustainability to preliminary designs?
(3) Identify and rate essential indicators or criteria deemed as important to the concept of sustainability in the engineering profession (projects or organisations)

Chapter 9
Questionnaire topic 1
Demographics including age, gender qualifications, experience
Questionnaire topic 2
Personal understanding of sustainability what is the engineer's awareness of sustainability definitions and assessments? What are the engineer's perceptions of sustainability?
Questionnaire topic 3
Rank essential indicators or criteria
Questionnaire topic 4
Descriptive open-ended perception questions, Discover previously unnamed factors. What is the engineering perspective on applied

Table 1-3: Mapping research questions

1.5 Overview of thesis structure

This thesis is organised in the following way:

Chapter 1: Introduction: Defines the problem, develop research aims, objectives and research hypothesis.

Chapter 2: Gives a general description of sustainability, undertake a literature review in relation to the many definitions and conclude with an engineering definition.

Chapter 3: Presents a detailed literature review of the various sustainability metrics regimes and indicator measurement concepts available.

Chapter 4: Investigates the interrelated issues between the profession, the engineering ethical predicament and relationship with sustainability highlighting the general methods in dealing with liability.

Chapter 5: Describes the specific issues and techniques used in engineering design and propose a new method to incorporate sustainability..

Chapter 6: Describes sustainability ideologies and a method, its properties, complexities and sensitivities.

Chapter 7: Identifies the significant sustainability criteria in the engineering context found in previous chapters and classifies these criteria.

Chapter 8: Describes the research methodology used for collecting and analysing data used to test perception and importance of sustainability criteria.

Chapter 9: Presents data analysis and discussion on the use of results of the questionnaire findings.

Chapter 10: Presents a conclusion that includes further research and recommendations perceived as feasible to further the knowledge in this domain. At the end of the thesis, there is a list of references and 8 appendices, including the questionnaire used.

Chapter 2. Sustainability Definitions

2.1 Outline

This chapter presents the literature review for this thesis. It begins by discussing and exploring the plethora of sustainability definitions and discussions. Upon completion of this review for the inquiry, the key findings are combined to explore their potential and applicability for devising an assessment tool for effective use in the management of engineering and technology.

2.2 Background

I would like to start this important discussion by referring to (Newberry, 2007) accounts of the Grimm's fairy tale The Elves and the Shoemaker. It is a story which likens the elves to engineers.

> "Who are, at least in one sense, responsible for the design and production of nearly all the artifacts of modern life? As with the elves, the engineer's role in the existence of most of these artifacts remains largely a mystery. Florman (1987) called engineering the anonymous profession. There are certainly some high-profile technologies that are easily associated with engineers, such as the Space Shuttle or a suspension bridge, for example; but there are countless others about which people rarely make a conscious connection with engineering, such as a paper clip, an electric shaver, or the kid's favourite jelly (babies, beans, snakes) or any piece of candy. But principally, I want to focus attention on what is perhaps a more enigmatic aspect of Newberry's fairy tale: little indication is given in the story about why the elves did what they did. Night after night, they made fine shoes for reasons unknown. In so doing, they substantially transformed the lives of the shoemaker and his wife. Did they do it: out of kindness? For some future payment? For the enjoyment of the work? For the pride of accomplishment? Likewise, the work of engineers, carried out largely behind the scenes of daily consciousness, transforms lives on a grand scale. But unlike in the fairy tale, in which the elves' efforts result, whether intended or not, in happiness-ever-after, the appraisal of engineers' work is more varied. There is certainly much in that work to be commended. But there is also much that is rightly eyed with ambivalence, and some is even condemned. So, whereas we might be content in our ignorance of the elves' motives, we cannot be so with those of engineers"

Reflecting on Newberry story, it can be said that engineering, as an element of technology as a social process, is actually changing the world in the words of (Goldman, 1991). The fundamental role of engineers and technology in the economic and political arena has a direct relationship with the perception of our natural resources. So the question is asked,

- Are engineers ultimately to be praised or blamed for development?
- Do engineers understand that the product of their work could lead to sustainability or vice versa?

Surrounded by this realm of thinking we set out to investigate in the next section the sustainability classifications in literature in order to compile a unique and universal operational definition of sustainability applicable for engineering.

2.3 The definitions of sustainability

The original WCED (Bruntland, 1987) publication invoked public interest in sustainability, posing challenges such as the management of contractive problems and acceptance that the world is faced with an environmental crisis, therefore a fundamental change must be made to overcome the crisis, for example, growth versus limits, intergenerational versus intragenerational equity, and individual versus collective interests (Dovers and Handmer, 1995). The Brundtland Commission Report, Our Common Future, provides the authoritative definition of Sustainability and Sustainable Development, and this definition makes much sense with regard to what we must all do to achieve even a modest degree of Sustainability. Figure 2-1 describes a mind map of the events leading up the Brundtland report. Essentially, from the time when sustainability was first popularized by the Brundtland Report in 1987, to the present day, numerous efforts have been made by different groups, organizations and individuals to capture a common interpretation of the concept.

> "Few concepts have been applied with less precision and consistency in policy circles than sustainability". The concept is now espoused at all levels of government and industry throughout the world, though rarely in a uniform way. This has been noted by some, including (Gell-Mann, 1994), who suggest that, while ''today many people are busy writing the word 'sustainable' in pencil, the definition is not always clear'' Additionally, (Costanza, 1994) asserts that ''to a large degree the sustainability concept is not internalised and the ramifications of internalisation are poorly stated (Meppem and Gill, 1998)".

Instead of focusing on the linguistic differences of definitions, the review focuses on answering research questions, and analysing each of the definitions:

(1) What are the main challenges for sustainability (sustainable practices) in Engineering?

(2) What is the basis for sustainable practices in Engineering?

(3) What is the common platform for sustainable practices in Engineering?

(4) What are the key instruments for sustainable practices in Engineering?

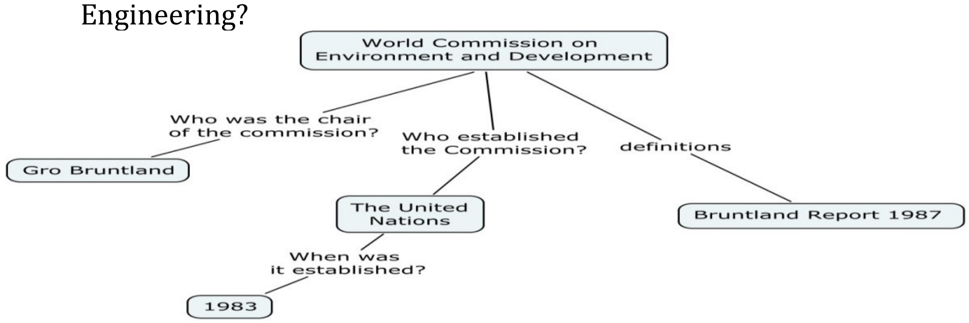

Figure 2-1: The origins of the Brundtland report

Kates et al. (2001) described the new of science sustainability as one that seeks to understand the fundamental character of interactions between nature and society and to encourage those interactions along more sustainable trajectories.

In addition Matson et al. (2007) went further to integrate physical, biological, and social sciences as well as medicine and engineering. Therefore with the development of the new science of sustainability over the past decade, it has been complemented by supporting infrastructure for example we have witnessed the integration of the concept across many schools, universities and governmental agencies in Australia and abroad. For instance, examples in academia include;

Central Queensland University's Department of Sustainability incorporates engineering schools similarly in the United States of America; Stanford University Department of sustainability and Energy management, also at the beginning of the academic year 2007, Harvard University commenced a Sustainability Science degree program. Harvard reported that it was seeking to advance a basic understanding of the dynamics of human-environment systems; to use that understanding to facilitate the design, implementation, and evaluation of practical interventions that promote sustainability in particular places and contexts; and to improve linkages between relevant research and innovation communities on the one hand, and relevant policy and management communities on the other.

Governmental; the Victorian government's Department of Sustainability and Environment, was created to realise the Victorian governments vision of sustainable development, its mandate covers water resources and catchments, climate change, parks forests, and ecosystem conservation.

Finally the number of annual publications is increasing linearly, and therefore, the accumulated number of publications is increasing exponentially. Figure 2-2 shows the number of papers which include the words ''sustainable'' or ''sustainability'' in the title or abstract where the Black circles and white circles are the number of annual publications and the accumulated number of publications, respectively, present a contextual perspective. Furthermore, Appendix A lists a variety of academic journals which have been launched to meet both the academic and social demands of sustainability, since the early 1990s. Therefore, the literature presents a lengthy debate on the definitions of sustainability. Furthermore, sustainability is offered as an intersection of three domains: economic, environmental and social which comprises equity and justice, as well as a cultural and spiritual meaning in equal measure. This vagueness in definition also conveys shortcomings in grasping the overall structure of sustainability for engineers. For example, to institute a thesis of this discussion, one must reflect to question what is sustainability in engineering and what does it include? But, grasping the current status of sustainability definitions has become an urgent task because of the growing body of journals as detailed in Appendix A,

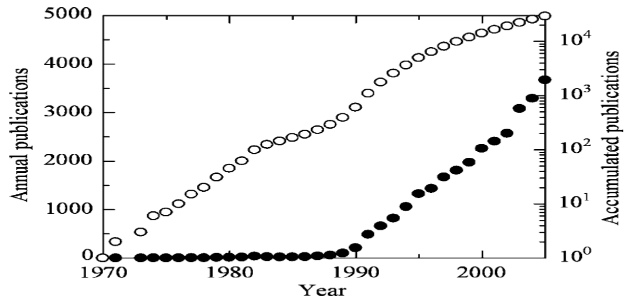

Figure 2-2: Number of papers (Kajikawa et al., 2007)

Before discussing how to advance sustainability in engineering, it is first necessary to be clear about what it is. The following section presents citations, scheduled in Appendix B, where sustainability publications are classified into five groups: the identity number, the year of publication, the main or first author and a brief description of the findings, followed by a objective classification of the definition, where S-Systems, N-natural, E-economic, T-technology, S-social. Whilst I recognise that it would be a cumbersome task to cover exhaustively all the definitions that are mushrooming from literature, the next section will classify the existing variety of definitions of sustainability into four major groups, depending on the constituent representation reflected. These are:

(1) Institutional systems based,
(2) Ideological stewardship Version,
(3) Academic Version and
(4) Physical version; economic social, natural, technology.

2.3.1 Journal periodicals search

In order to examine the growth and development of the literature on "sustainability" research, we use electronic databases to collect citations from all journal periodicals and newsletters matching specified keywords featuring ''sustainable'', ''sustainability'' in titles covering environmental communication topics in social science journal literature from relevant indices. The indices used were: the Institute for Scientific Information's (ISI) Ulrichsweb Abstracts Citation Index (Web of Science), and Periodical Abstracts (Pro-Quest Direct). To gather citations a search word combination used in the search terms were "sustainable" and "sustainability".

2.4 Sustainability definitions in the discussion

Acknowledging the lack of an agreed definition of sustainability, (Mebratu, 1998) proposed that there were three main "versions" of sustainability: institutional, ideological, and academic, as shown in Table 2-1. However, the normative interpretation most widely quoted is that expressed by the (Bruntland, 1987) World Commission on Environment and Development. It is also useful at this point to review some of the more considered articulations of the sustainability concept. Since the Bruntland report various definitions have been suggested, which are all very similar, yet are open to interpretation and still remain somewhat ambiguous for application in engineering.

According to Meppem and Gill (1998) definitions can be classified in either positivist or normative terms. Keynes declared that a ''positivist science may be defined as a body of systematised knowledge concerning what is; a normative or regulative science as a body of systemised knowledge relating to criteria of what ought to be.. Leal Filho (2000) reported the expression “sustainability” has been traditionally used as synonymous with words such as “long-term”, “durable”, “sound” or “systematic”, among others.

Indeed, in the context of the English language, sustainable development is very often referred to as “durable development” in French, while word-by-word translations are found in the German (nachhaltige Entwicklung), Spanish (desarrolo sustenible) and Portuguese (desenvolvimento sustentaÂvel) languages. Sustainability is defined differently within and between cultures, and its definition has changed over time(Kesik, 2002).Hence, by the reviewed definitions, sustainability is interdisciplinary and cannot be set into one area.. The concept of sustainability is a complex one (David et al., 2006) hence it is not possible here to deal with all of the definitions and interpretations of sustainability. However, it is possible to distil the fundamental characteristics by assuming a universal analysis. For the purpose of this investigation,

> “A system is simply defined as a set of interrelated elements or subsystems, the elements can be molecules, organisms, machines or their parts, social entities, or even abstract concepts. The interrelations, interlinkages, or couplings between the elements may also have very different manifestations flows of matter or energy, causal linkages, etc” (Gallopín, 2001).

The word ‘sustain’ has a historical presence in the language. It is derived from ‘sustenare’, Latin meaning "to hold up" i.e. to support. today, it is common use extends to keep something going, with an a suggestion of providing of extending duration (Sutton, 2004); sustain meaning to cause to continue (as in existence or a certain state, or in force or intensity); to keep up, especially without interruption diminution, flagging, etc.; to prolong (Webster, 2006).
The most frequently cited definition of sustainability, which is considered as the modern genesis of the sustainability movement, as shown in Figure 2-1.

> “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”Bruntland Report (1987)

However Marshall and Toffel (2005) had criticized this definition as being difficult or impossible to operationalize and implement. We add that how should this definition be used to evaluate engineering practices or business decisions? Furthermore according to Holmberg (1996), by 1994 there were more than 80 different definitions and interpretations fundamentally sharing the core concept of the WCED’s definition. In addition “By the mid-1990s, there were well over 100 definitions of sustainability” credited to Elkington as cited by Marshall and Toffel (2005) Finally, I was unable to validate either of their claims but what I can say is that I have accounted for 60 definitions in the literature. Given that the purpose of this review was to explore the vast interdisciplinary array of interpretations of these definitions and not to quantify them. In conclusion, a definitional consensus is made that sustainability is not a problem, nor an end point; it is rather a process and a vision involving renewed awareness of the natural environment.

> “In the age of information it is a journey to destination unknown, an evolving process of a development in all aspects of life and sustenance, more often it requires concurrently resolving competing

goals in quest of social, ecological, economic with is the resultant vector being technological development. However, the destination is not a fixed place in the regular sense. Today, it is characterised as desired a features for a the journey"

Institution	*Drivers*	*Solution epicentre*	*Solution platform*	*Instruments (Leadership)*
WCED "World Commission on Environment and Development"	Political consensus	Sustainable growth	Nation-state	Governments and international organisations
IIED "International Institute for Environment and Development"	Rural developmen t	Primary environmental care	Communities	National and international NGOs
WBCSD "World Business Council for Sustainable Development"	Business interest	Eco-efficiency	Business and industry	Corporate leadership
Ideology	Liberation theory	Source of environmental crisis	Solution epicentre	Leadership centre
Eco-theology	Liberation theology	Disrespect to divine providence	Spiritual revival	Churches and congregations
Eco-femininism	Radical feminism	Male-centred epistemology	Gynocentric value hierarchy	Women's movement
Eco-socialism	Marxism	Capitalism	Social egalitarianism	Labour movement
Academic discipline	Drivers (epistemolog ical orientation)	Source of environmental crisis	Solution epicentre	Instruments (mechanism of solutions)
Environmental economics	Economic reductionism	Undervaluing of ecological goods	Internalisation of externalities	Market instrument
Deep ecology	Ecological reductionism	Human domination over nature	Reverence and respect for nature	Biocentric egalitarianism
Social ecology	Reductionist-holistic	Domination of people and nature	Co-evolution of nature and humanity	Rethinking of the social hierarchy

Table 2-1: Institution, ideology and academic versions of sustainability (Mebratu, 1998)

Johnston (2003b) supported the analogy of process not a destination explaining the concepts of Biocentric or Anthropocentric. The basic divide in the debate on sustainability and sustainable development is between approaches which can be characterised as anthropocentric (human-centred) and biocentric (concerned for all living things). The latter treats human life as part of the whole system of life on Earth; its focus being on maintaining the integrity of all of nature's processes, cycles and rhythms. On the other hand, those following human-centred approaches emphasise human standards of living and are more willing to trade off the interests of other species. Similarly, Figure 2-3 illustrates in simple terms the concept of strong and weak sustainability with its four dimensions. Essentially, the four dimensions listed in Figure 2-3 also include the institution at a local, national and international level, since good governance at the international level is fundamental for achieving sustainability.

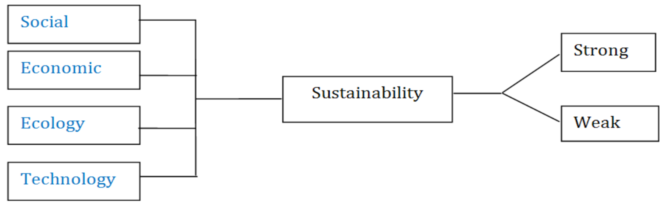

Figure 2-3: The fourth sustainability factor being technology (Hasna, 2007b)

2.5 Why sustainability?

In today's world, sustainability has been assigned a high level of importance because it is now realised that without it, there is a great deal of uncertainty. As indicated by the planet's serious ecological problems which have persisted since the Brundtland Commission in 1987 to the recent Global Environment Outlook: environment for development-GEO$_4$ report (UNEP, 2007), prepared by 390 experts and reviewed by 1000 others. It reported scientific facts that supported global warming and resource depletion.

2.5.1 Prism models of sustainability

A number of sustainability conceptual models have become popular since the Brutland report The World Bank 'capital stock model' Keiner (2005) which promotes a simplistic idea of living off the interest and not the social and ecological capital.. The equation is:

$$CSD = \sum CE_n + CE_c + CS \qquad (2.1)$$

Where;

CSD=Capital stock of sustainable development
CE_n =Capital stock of the Environment
CE_c =Capital stock of the Economy
CS = Capital stock of the Society

This equation perspective is yet to be explored from an engineering design perspective. This equation can be traced from a simple model used to facilitate the concept of sustainability, the triangle of environmental-conservation, economic-growth, and social-equity dimensions, sometimes also shown as three interlocking circles, as per Figure 2-4. This model is also called the 'three pillar' or 'three circles' model covering the survival essentials of society.

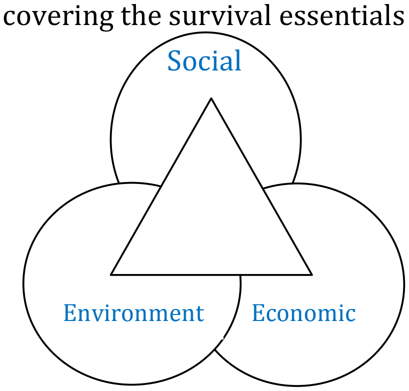

Figure 2-4: The three pillar (triangle) basic model of sustainability (Keiner, 2005)

A number of advances were made in the three dimensional theory among the most attention-grabbing one was the prism model. The 'prism of sustainable development' adapted from (Spangenberg and Bonniot, 1998; Valentin and Spangenberg, 1999) describe four main dimensions:

- Economic dimension (man-made capital);
- Environmental dimension (natural capital);
- Social dimension (human capital) as the base for;
- Institutional dimension (social capital)

In each dimension of the sustainable development prism shown in Figure 2-4 there are indicators used to measure sustainable development (Valentin and Spangenberg, 1999). A number of authors criticized this prism model arguing that economic dimension is not independent since it includes assets from all four dimensions. Consequently, the same author proposes a "MAIN" prism of sustainable development.

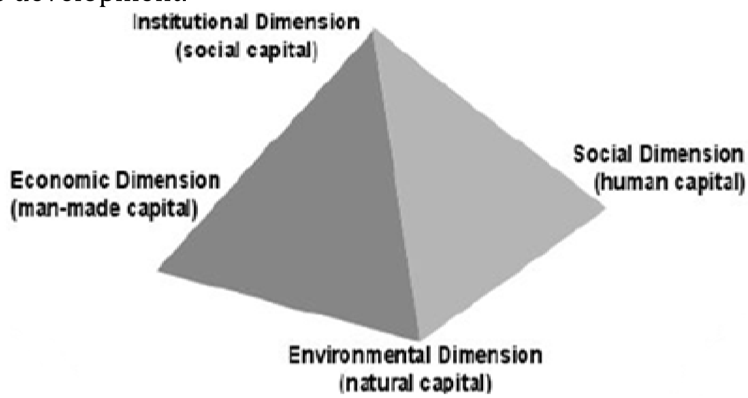

Figure 2-5: The prism model (Stenberg, 2001)

In this model, the following new term Institutional was introduced

- The environmental dimension includes natural capital non-renewable and renewable.
- The economic dimension (artefact) refers to products i.e. bridges, cities.
- The social dimension includes human capital knowledge, and experience.
- The institutional dimension refers to the organization of society

One of the major criticisms of the two prism models presented in this section are the expected simultaneous growth in all dimensions, which Is not practical and deemed as an inherent physical limitations of the model.

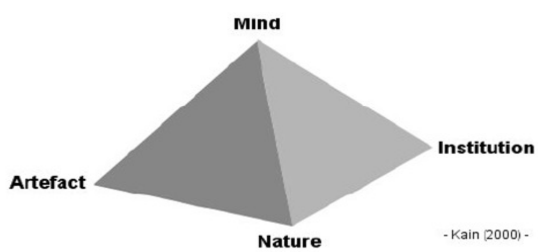

Figure 2-6: The prism of sustainable development (Stenberg, 2001)

2.5.2 Factors effecting sustainability

The reviewed literature uncovered a spectrum of definitions for sustainability. In the interest of simplification, various results (factors effecting sustainability) were grouped in a systematic model, in terms of value which equals to importance multiplied by priority, as shown in Figure 2-7,since the system in which we live in, "planet Earth", is a finite system, and as such has constraints.

The physical reality is therefore subject to constraints which determine our limits

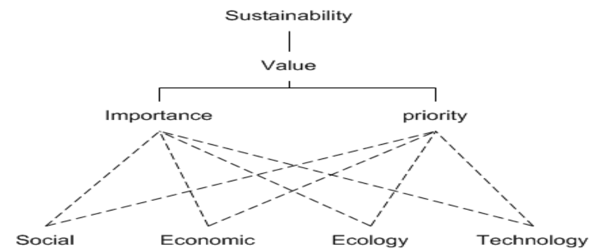

Figure 2-7: Typology of sustainability (Hasna, 2007b)

Table 2-3 provides a basis for the evaluation of environmental constraints to establish a big-picture context and a strategic direction which are based on scientific knowledge in literature.

	Sustainability
Constraints	Resource harvest must not be less than managed or natural regeneration rates
	Environment waste less than natural/managed assimilation rates
	Optimize environmental services -use over indefinite time periods
	Time frame = "very long" or "indefinite
	Future generations -no worse than current generations
	Future living standards - not impaired by current decisions
	Future generations' rights - institutions and policies
	Natural resources -sustainable use of inputs over time
	Processes – steady state, processes renewable
	Future living standards - not impaired by current decisions
	Economic systems managed to live off dividends. Asset base maintained or improved
	Natural resources -not necessarily preserved in any particular state

Table 2-2: Process constraints (Hasna, 2007b)

Newman (2003) described and expanded on the trilogy concept of sustainability to include the common boundaries between the three pillars as the basis of his argument where as Figure 2-8 is a summary of the most frequently mentioned objectives, factors, boundary conditions, constraints and mechanisms.

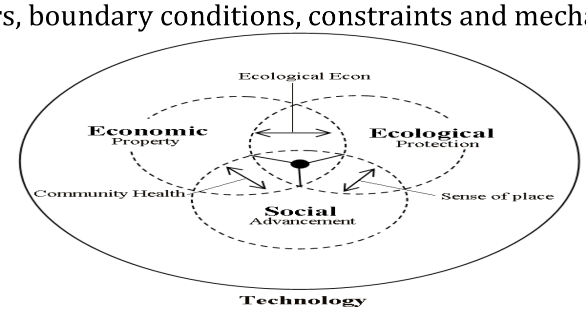

Figure 2-8: Sustainability enveloped in technology adapted from (Newman, 2003),

Figure 2-8 illustrates the overlapping themes of sustainability factors: ecological economy, community health and sense of belonging which are all part of the human economic systems and ecological systems both interrelated, enveloped by technology, where for example, any use of a non-renewable resource is considered shifting the symmetry to be unsustainable (effect). Table 2-3 provides a summary of the most cited sustainability factors and objectives in literature. These include

- Factors; social, economic, ecological and technological,
- boundary conditions ; culture; society, equal access to the resources, human species indefinite survival, present humans; satisfaction.

The off sequence of all of these sustainability models and objectives reviewed thus far is the difference between the two focal asymmetries, for instance the pace of technological growth is faster than the biological metronome. Hence in an ideal world we would need to create a steady state conditions to achieve sustainability. This can be achieved by slowing society growth to stay in sync with entropic process. Ultimately this frame of thinking would favour decentralization of society to smaller scale units to create energy efficient enclaves using renewable resources.

Sustainability Objectives	
Definitions	Relationship between technology and its context
	Inexact concept that cannot be measured
	Ability of a system to function indefinitely without decline
	Nexus of relationships between many elements, requires interaction of all variables
	Integration of the three types of sustainability: social, economic, environmental,
	Continued productive potential, particular management system
	Ability to maintain activity despite stress or shock
	System state, no violation of internal or external constraints, stability, future, stakeholder needs, impact on resource base, impact on ecosystem
	Transformation of assets and opportunities, fairness, generations, portfolio of assets , industry , adaptation , social and environmental paradigm , industry and environment intertwined , resource consumption, waste , altering the environment , adaptation.
	Doctrine, economic growth and development maintained over time within ecological limits, interrelation of social and natural laws , environmental and economic development are complimentary

Table 2-3: Most represented themes in literature (Hasna, 2007b)

Propagating sustainability today has resemblance of predicting or forecast the future, to realise this importance, let us visit some of the extracts conveyed by eminent persons in history to view their success in predicting the future. It was Lord Kelvin, physicist and the president of the Royal Society, 1897, who said "Radio has no future" (Laven, 1998). Thomas Watson, Chairman, IBM, 1943 "I think there is a world market for maybe five computers" (Richter, 2001). Ken Olson, President, Chairman and Founder of Digital Equipment Corporation, 1977 said, "There is no reason anyone would want a computer in their home" (Viswanath and Brown, 2001). According to (Sharma, 2006), anyone can say that these statements merely indicate their inability to foresee the revolution that these technologies could bring about to human society.

2.5.3 Attitude towards sustainability

A key question asked by Leal (2000) is why sustainability, as a process, is so difficult to understand in some contexts? The following are examples of some of the criticisms cited in literature. it was claimed by the following authors (Costanza,1994; Leal Filho,2000; Martens,2005; Martens,2006), that:

(1) sustainability is not a subject per se since it is not classified as being of the domain of any given science;

(2) sustainability is too theoretical;

(3) sustainability is a too broad, engineering profession, where the subject is seen as too broad and, by default, impossible to handle;
(4) sustainability is too recent a field; and
(5) sustainability is a fashion.

There are various reasons that influence attitudes towards sustainability, as listed in Table 2-4. For example, some of the confusion on sustainability science exists due to the lack of clear-cut information.

Knowledge	Information on the meaning of sustainability and its implications
Background	The nature of his/her training often influences an individual's degree of receptivity in relation to sustainability
Experience	Previous experience with environmental and social affairs facilitates understanding of the role of sustainability
Perception	The integrated view of environmental, political and economic elements enables a broader perception of sustainability
Values	Differing from the previous ones due to their high degree of complexity, an individual's values often determine whether attitudes are favourable or otherwise
Context	Sustainability is not only related to ecological components per se, but also entails items such as economics, politics and social matters. However, links with the latter are often ignored by universities

Table 2-4: Some factors which influence attitudes towards sustainability(Leal Filho, 2000)

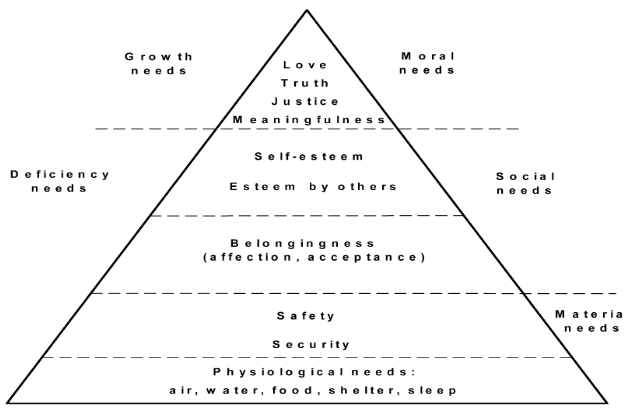

Figure 2-9: Maslow's hierarchy of needs

Of all the discussions which attempt to relate the social benefits of products and services to satisfying human needs, perhaps the best known is (Maslow, 1954), who articulated the hierarchy of human needs, summarised in Figure 2-9. The common interpretation is that higher level needs remain latent until the lower level needs are satisfied, although there is some question as to whether Maslow himself intended this interpretation.

2.5.4 Characterization of sustainability

O'Riordan (1988) shows that various interpretations of social change influence the characterisation of sustainability and that there is a distinction between sustainability and globalisation. He also explains different angles on sustainability, emphasizing how discourse varies in disciplinary perspectives, each discipline views political, ecological, economic, anthropological, legal and sociological from self perspective. Table 2-5 and Table 2-6 are comparative tables for translating these interpretations into discourses on globalisation and localisation where the headings in both rows and columns match the critical success factors listed previously in Table 1-2. The Institution of Chemical Engineers(IChemE, 2002) ''Sustainability Progress Metrics'' recommended for use in the process industries follows O'Riodan approach, including social indicators which aim to reflect ''the company's attitude to the treatment of its employees, suppliers, contractors and customers and also its impacts on society at large''. More contentiously, the IChemE indicators include the disparity of income and benefits between the company's direct employees. However, none of these indicators addresses the social value of the products or services which a company provides.

	Market	Regulatory	Equity	Revelatory
Myths of nature	Expandable	Precautionary	Breached	Negotiated
Social values	Limits	Limits	Limits	Limits
Policy orientations	Price signals	Rules of contracts	Opportunity	Communication
Distributional arrangements	Markets	By agents of rule-makers	By democracy	By negotiation
Generating consent	Compensation	By agreed rules	Negotiation & compensation	By reasoned discussion
Intergenerationality	Future looks after itself	Future helped by present	Future planned by present	Future envisioned
Liability	Spread losses	By redistribution	Burden-sharing	By negotiation mechanisms

Table 2-5 : Discourse patterns that apply to sustainability transition (O'Riordan, 2001)

To take an obvious, if extreme example, a company producing ''weapons of mass destruction'' might operate in a way which appears to be benign in terms of these social indicators, but that would not justify the company's activities. To take a less extreme example, if I were to buy a gun and shoot a colleague, writes (Clift, 2003), it would be no consolation to his family to know that its manufacturer operates to sound ethical standards; equally, it would be of little interest that I used ''environmentally friendly'' lead-free bullets with low Ecometrics Values.

	Market	Regulatory	Equity	Revelatory
Globalization	Expandable limits	By agents of role makers	Mixed scanning for vulnerable	Evaluation of social responsibility
	Competitive advantage	By common agreement	Reliance or global watchdog activities	Corporate and governmental
Localization	Initiative	Precaution and pragmatism	Social-local identity	Deliberative and inclusionary procedures
	Opportunism through social markets	Links to global standards negotiated by local stakeholders	Local citizenship initiatives through social networks	Social commitments to participatory involvement through best value procedures

Table 2-6: Patterns of discourse on globalization & localization (O'Riordan, 2001)

2.5.5 Sustainability and environmental law

One potentially vital paradigm shift in the drive towards sustainable engineering practices is to move from environmental law to sustainability law, as detailed in Table 2-7. Sustainability law would not be concerned merely with mitigating the damage inflicted by industrial economies and western lifestyles, rather sustainability law would focus on transforming the relationship between humans and the natural environment from one based on minimizing harm to one based on maximizing harmony. Instead of asking if we can limit the ecological damage caused by contemporary industrialized society, sustainability law asks if we can do things in a completely different way that avoids creating environmental problems in the first place. Sustainability law will challenge the belief that human activities must inevitably damage the natural world. Can't human beings strive to do well, instead of merely aiming to be less bad? In the words of world-renowned green designers

> "to be less bad is to accept things as they are, to believe that poorly designed, dishonourable, destructive systems are the best humans can do. This is the ultimate failure of the "be less bad" approach: a failure of the imagination(McDonough and Braungart, 2002),"

Environmental Law	⟺ Sustainability Law
Mitigates	Transforms
Short-term	Long-term
Reactive, crisis-driven	Proactive, precautionary
Ad hoc	Systemic
Incremental	Radical
Fragmented	Holistic
Unscientific	Ecological
Prescriptive	Results-oriented
Rigid	Adaptive
Confrontational	Cooperative
Narrow	Diverse, pluralistic
Ineffective, inefficient, inequitable	Effective, efficient, equitable

Table 2-7: The contrast between environmental and sustainability law (Boyd, 2005)

2.6 Sustainability and engineering philosophy

As a starting point for this discussion the question is asked why is philosophy important to engineering?

> "Ultimately and most deeply, it is because engineering is philosophy - and through philosophy, engineering will become more itself"(Mitcham, 1998).

A philosophy of engineering also forms an ideological structure so that engineers know where they stand with relation to issues of economic and moral importance that they may face and, more importantly, to make sensible judgments when such issues are presented. A philosophy of engineering, where philosophy is in its true and disciplined sense, is as important to the engineering profession as an engineering mission statement is to an engineering firm. Like a mission statement, a philosophy of engineering provides a direction for development and a professional identity. Definitions of philosophy can be thought of as related; we can extend the mission statement to a more encompassing view of a philosophy for the engineering profession, and all engineers. A philosophy of engineering could include elements of many other different philosophies; a mosaic of philosophy types in order to achieve the best result.

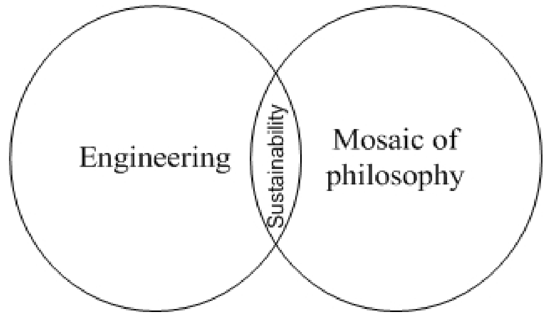

Figure 2-10: Merger of entities with hypothesis by-product (Hasna, 2008a)

Therefore, for the engineering profession to facilitate a healthy relationship with technology and the wider community, it needs break out of the cycle and focus, as the purpose of technology, to provide a better standard of living (Heidegger, 1977). Indeed, a balance of many of these philosophies would make for good engineering management, but more so in the way that they would simply make us good human beings. Thus, through the function of this philosophy of engineering, engineers will be better equipped to deal with the external values placed upon them and help them provide acceptable engineering solutions for the society in which they work.

> "The international community as a whole is involved in a global search for new modes of development, new designs for social interaction, and new technologies for meeting evolving needs, wants, and demands (Kesik, 2002)"

To promote the sustainability the United Nations has assigned 2005-2014 as the decade of Education for Sustainable Development (DESD). This global agenda of sustainability is therefore not likely to go away and the engineering profession must address.

> Engineering, in the past, may have been historically and socially constructed so as to alienate philosophy.. Philosophy, in the past, may also have sought to keep engineering at bay (Alavudeen et al., 2008; Mitcham, 1998)

As shown in Figure 2-11. But times and the world have change. With the advent of DESD the engineering profession has certainly changed and remains to evolve around the needs of both society and industry.. Indeed, engineering education is more accepting of the needs of alternative philosophies.

Figure 2-11: Engineering and philosophy model

2.7 Economic context

This chapter had examined sustainability definitions and their development in literature. The objective of this chapter was to provide an overview of some key contexts of the sustainability discourse. From the above section we have noted sustainability definitions explaining both linear and circular economic dimensions; these dimensions endorse two independent economic models, primarily growth and steady-state.

> “Growth proponents describe production/consumption and supply/demand in circular flow terms while minimizing the linearities of resource depletion by means of beliefs in the fecundity of the market to produce substitutes when depleted resources become too dear. On the other hand, linearity is reflected in growth model assumptions with which increasing levels of well-being are directly correlated, linearly increasing consumption levels”(Carpenter, 1995).

Highlighting the main assumption of steady-state theory in relation to the linear second law of thermodynamics, we can deduce a definition of economic sustainability in terms of limits to the technological resource base, i.e. increase in entropy. Ikerd’s (1997b) model explains that things are "obviously mechanical", interconnections are weak, dynamics are indiscernible, and order dominates chaos. For such phenomena, mechanical models work well. However, for things "obviously biological", inter-connections are strong, dynamics are undeniable, and chaos often seems dominant over order.

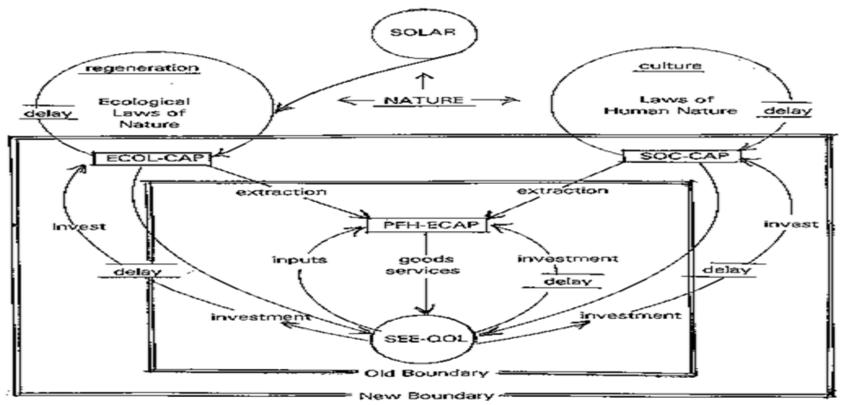

Figure 2-12: Economic model of sustainability (Ikerd, 1997b)

The principal difference in the biological economic model illustrated in Figure 2-12 from the "old" mechanical model of economics, is the inclusion SEE-QOL where

SEE-QOL: Social, Economic, Ecological: Quality of Life;
PFH-CAP: Physical, Financial, Human: Economic Capital;
SOC-CAP: Social Capital and
ECOL-CAP: Ecological Capital.

To ensure economic sustainability (Ikerd, 1997b) included "new" boundaries social and ecological capital, his model represented "people" rather than "consumers, where as ‘consumer’ and ‘producer’ relate only to the economic dimension of people. He signified that quality of life has economic, ecological, and social dimensions. Moreover, the main principle in economic capital build up is to improve the extraction route, not to reconstruct extended social or ecological capital stocks. The core characteristic of Irerd’s model is that human progress is essential characteristic of quality of life.

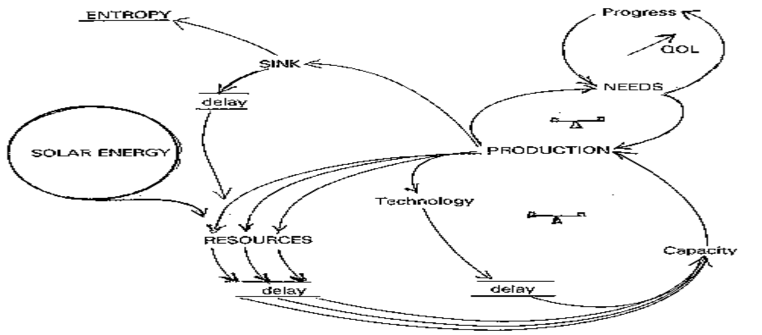

Figure 2-13: Sustainable system (Ikerd, 1997b)

> “The new paradigm represents a conscious attempt to move away from the convention of converting everything into "economic" terms, such as human capital and natural capital, instead using the more neutral term, resources. Investments in technology can enhance, but not replace, the ability of resources to support production and meet the needs of people” (Ikerd, 1997b).

Ikerd’s (1997b) proposed a basic model of a sustainable economic system as shown in Figure 2-12 the flows in this model are simplified in Figure 2-13. The simplified model is made-up of interaction of cycles of human needs, production, solar energy, technology resource and sinks to sustain production and meet the needs of people. The needs of people include but not limited to quality of life individual, shared and spiritual in nature, as shown in Table 2-8.

> “The needs that are not unique to any individual but must be realized collectively with some larger community of interest”(Ikerd, 1997b).

Needs	Resources	Allocation
Individual	Economic Social Ecological Technology	Market/private
Shared		Collective/public
Spiritual		Ethics/rules

Table 2-8: Shared needs

2.8 Conclusion

Ontology is a collection of concepts and relationships in a specific domain (Badal et al., 2004). Sustainability ontology has moved from a concept used more as a policy guide to a true science-state approach with a sound scientific basis. Furthermore, sustainability ontology can also be seen as large taxonomies. Sustainability science exists in relationships, and its stature is confirmed by the theoretical and practical perspectives offered in the definitions, periodicals and journals, academic qualifications, linguistic developments, and metrics. The perceived value of sustainability as a discipline in the scientific community is confirmed by the upsurge of new text books, SS journal titles, and the linguistic fluency of SS. The results of these findings are summarized in Table 2-9.

The literature is divided into three phases: the mid-1970s hub which was a response to the limits of growth; the mid-1980s which observed the emergence of sustainable development literature; and the mid-1990s which focused on clarifying the distinction between sustainability and sustainable development.

Nowadays, in the first decade of the 21st century, we are witnessing a fusion of the previous three decades of research materializing as a new domain. New Scientist Special Report: The folly of growth? (2008), reviewed twelve recent books on economic growth and overconsumption, and the consequences for environmental sustainability (Goerner et al., 2008). The New Science of Sustainability proposes that as a science or discipline, sustainability is, as one expression of interactions between natural and social systems, a healing response. According to Parkin et al. (2003), 200 definitions of 'sustainable development' exist, and also 61 sustainability definitions(Hasna, 2007b).

Taxonomy	Component	Number	Units
Knowledge	Sustainability Definitions	61	Definitions
	Sustainability Periodicals and journals	117	During 2008
Comprehension	Sustainability related papers	3000	Annually
Application	Institutional policy (Kyoto)	Unlimited	Unlimited
Analysis	Linguistic reference	35000	Citations
	World wide web presence (search engine)	60	million
Synthesis	Sustainability degree programs in OECD	15	Programs
Evaluation	Sustainability Metrics-assessments (indicators)	60	2008
	Sustainability software tools	21	2008

Table 2-9 Summary of sustainability science findings

According to Holmberg et al. (1996), by 1994 there were more than 80 different definitions and interpretations fundamentally sharing the core concept of the WCED's definition. By the mid-1990s, there were well over 100 definitions of sustainability (Marshall and Toffel, 2005). There seems to be as many published definitions of sustainability as journals and periodicals that carry either the name sustainable or sustainability in their titles. That is not to suggest these are the only published avenues of material dealing with this subject matter. However, if defining sustainability is difficult, putting it into practice is yet to be seen.

2.8.1 A personal reflection on definitional sustainability

> "As a concept, sustainability has captured our imaginations and aspirations as a tangible and identifiable goal it eludes us" (Fricker, 1998).

Sustainability is represented in social, economic, ecological and technology dimensions. In this chapter we have demonstrated that it is far more than just a link between the economy, society and the environment. Whilst interconnectedness is a significant attribute, SEETT remain largely represented as an external manifestations of sustainability. My endeavours in this chapter were two-fold: firstly to present literature citations and an interpretation of sustainability definitions and secondly to discuss these in an engineering context. It is of no surprise that I am unable to present a concise definition but, with reservation, I can state that sustainability is not a problem in the conventional sense in that it needs solution, nor an end point; rather, it is a process, as illustrated in Figure 2-12, a vision involving renewed awareness of the natural environment and interaction with it. Furthermore, I would like to refer to the example of two of the key heavy industrial areas in Australia - Gladstone (Queensland) and Kwinana (Western Australia). These industrial areas are home to alumina, nickel and oil refineries, pigment and chemical plants, aluminium smelters, cement industries, coal export terminals, power supply and the first commercial direct reduction iron making plant. These industries have a tradition of collaboration in areas of mutual interest, such as community relations, safety and environment. It is also encouraging to see resource synergies that provide a significant avenue towards sustainable resource processing, via exchanges of by-product, water and energy between companies; one chemical plant's waste being another plant's feedstock. There are also international examples of industrial symbiosis, for example Styria, Austria; Rijnmond, The Netherlands; Humber, United Kindom; Tampico, Mexico; Map Ta Phu Industrial Estate; Thailand and Alberta, Canada.

At its heart, sustainability is about relationships between human beings and the planet. Fundamentally, it forms the fibres of our moral fabric and human social union. Sustainability, therefore, may be a dynamic, a facet of Gaia theory. Finally, sustainability is a management methodology of how to prioritize our consumption of resources and hence minimise our footprint. Finally, I would like to end this chapter by referring to (Skinner, 2004) who highlighted the need for definitions of sustainability and interpretation to be ones that are everyday workable and that embody concepts of long-term endurance and continuance in spite of variability and even adversity in the contextual setting. According to Bagheri and Hjorth (2007), the major challenge in dealing with sustainability is to develop a means for practicing the paradigm in everyday planning and management of a society. It calls for proponents of human, economic, as well as environmental concerns to join together to provide an everlasting life for the human species in the global ecosystem. To this end, engineers need a tool by which to recognize the synergies and constraints among nature, economic activities and people; a tool or methodology that notifies of sustainable practice. Hence, this contributes to the theme of the thesis discussion on sustainability in engineering.

Chapter 3. Sustainability Assessment

3.1 Outline

Shifting from theoretical and definitional discussions in Chapter 2 to an operational level requires characterising and measuring the different aspects, and dimensions of sustainability. The following section reviews some of the extensive body of sustainability assessments. The aim of this chapter is twofold: firstly, to provide a literature review on the multitude of sustainability assessment tools, regimes, indices, metrics, and secondly to identify the drivers that are used within them.

3.2 Background

In order to appreciate sustainability assessment tools, it is vital to address the following questions:

i. What it is are we assessing?
ii. Why are we assessing it?
iii. What indicators are used to measure progress towards sustainability assessment?
iv. How are these indicators assessed? and
v. How are these indicators used?

Sustainability indicators became prevalent post the Rio Summit 1992.

> "traditional indicators such as GDP, GNP and unemployment rates failed to address issues inherent in the sustainability concept and therefore different measures had to be developed"(Farsari and Prastacos, 2002)

This was also the view of (Harding, 1998) he acknowledged that a more holistic approach is required and stated that traditional mono-disciplinary instruments are no longer appropriate for dealing with complex global environment issues (problems such as climate change) and interaction between many of the earth's ecosystems. As global environmental and ozone depletion increase is.

3.3 Approaches to sustainability assessment

Initially sustainability assessment theory was created on the basis of the concept of sustainability, or sustainable development, . For the most part the theory of sustainability assessment as expressed in the literature has evolved from two dissimilar approaches:

- Environment integrated assessment and
- Objective led assessments.

3.3.1 Environmental impact assessment

EIA has been around in legislation for 30 years (Sippe, 1999); The basic premise of an EIA is appraisal, specifically to identify and evaluates any possible , probable or potential environmental impact, and if appropriate propose mitigation measures to these negative impacts. Similarly an environmental integrated assessment approach to sustainability assessment is more or less the same as EIA , it aims to minimise adverse impacts, as shown in Figure 3-1. For example, to identify the triple bottom line (Elkington, 2004), environmental, social and economic impacts of a proposal are compared with baseline conditions (e.g. 'do nothing' option), after which it is then determined whether or not the impacts are acceptable. Hence, devising methods of making these impacts more acceptable results in modifications to the proposal to lessen the negative impacts.

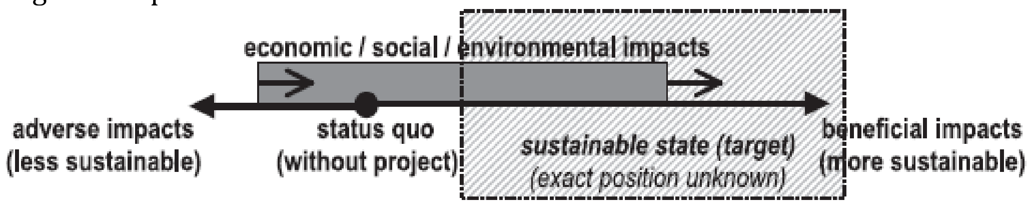

Figure 3-1: EIA driven integrated assessment (Pope et al., 2004)

Challenges and limitations

one of its major limitations being that it is a reactive process i.e. applied after a proposal has been developed, which is a late stage of decision-making, so many important decisions have already been made at higher levels of decision-making (Dalal-Clayton and Sadler, 2002).

3.3.2 Objectives-led integrated assessment

An objectives-led integrated assessment has its origins in objectives-led strategic environmental assessment, it mirrors a concept of sustainability as a goal, or progression of goals, to which society is aspiring. It echoes an aspiration to achieve a particular vision or defined outcome, it usually comprises of incorporation of environmental, social and economic objectives. Typically it assesses the proposal's degree of sustainability and how it contributes to this vision to; objectives-led integrated assessment is about maximizing the objectives, as shown in Figure 3-2.

Challenges and limitations

This approach is limited by architectural issues such as tiering, furthermore, the objectives must be constant and well-matched with each other, which represents a mammoth challenge task since it is not uncommon for objectives to be conflicting (George, 2001; Therivel and Partidario, 1996). Gibson (2001) went further to suggest that minimization of negative effects is not enough assessment must encourage positive steps.

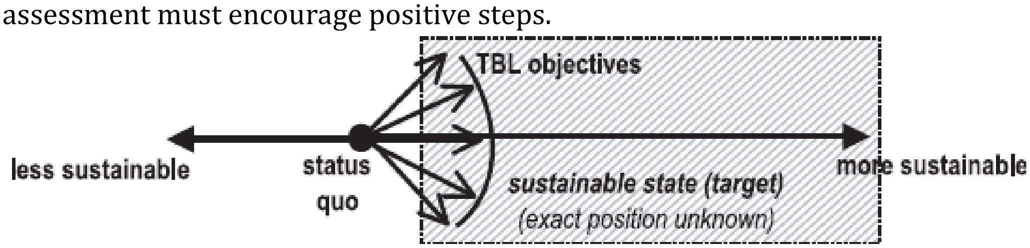

Figure 3-2: Objectives-led integrated assessment (Pope et al., 2004)

A discussion on sustainability assessment tools would not be complete without visiting the founding or traditional environmental decision-making tools. The next section deals with environmental decision making.

3.4 Environmental decision-making tools

Increased community awareness of environmental issues had given rise to the development of environmental decision-making tools had evolved as a result of and demand for product information covering the life of the product (Greene, 1992). LCA is one of the newest support tools and its role and status within the environmental field is still being refined (Udo de Haes, 2000). In determining the most appropriate characteristics of a support tool, as listed inTable 3-1, and bearing in mind that they are all important in their own right and are used in environmental decision making, the research required frameworks to be reviewed. LCA, CBA, EIA, RM and MCDM are all key decision-making support tools, the results of which should not be used in isolation. It is acknowledged that there is not one 'complete' environmental decision support tool and that often a combination of support tools is required to evaluate the technical, economic and social aspects of a process or strategy. Of the six tools, LCA is the most dynamic and flexible. Unlike EIA, which uses a static approach for a single point in time, LCA is flexible enough to account for 34 changes across different time periods. CBA and Risk Management are not as flexible and are limited in estimating future projections. All four tools provide a environmental decision making support for the decision-makers. In addition EIA, CBA and R M share social and economic dimensions and hence are able to asses these dimensions. However, LCA is considered limited in social and economic and has strength in technical assessment.

Abbreviation	Full name
LCA	Life Cycle Assessment
CBA	Cost Benefit Analysis
EIA	Environmental Impact Assessment
RA	Risk Assessment
RM	Risk Management
MCDM	Multi-Criteria Decision Making

Table 3-1: Environmental decision making

3.4.1 Life cycle assessment

Life-cycle analysis or assessment technique that originated in the 1960s but did not gain a wider acceptance until the 1970s (Stone, 1997) with its primary use in determining the environmental damage caused by a product or process it has also been known as 'Cradle to Grave Analysis', 'Eco-balancing', 'Materials Flow Analysis' and 'Life Cycle Thinking' (Roberts, 2003).

Typically the first stage of any (LCA) begins by defining the goal and scope of the proposal; this should be clearly defined to ensure what is and is not to be included in the study. LCA comprises four main stages (Lupis, 1999) goal and scope definition, Life Cycle Inventory Analysis (LCI) is the methodology of quantifying the inputs and outputs from the life cycle of a product or process, Life Cycle Impact Assessment (LCIA) is the qualitative and/or quantitative process to characterize and assess the effects of the environmental loadings identified in the inventory component., and interpretation of results (includes improvement analysis), for further details on the steps please refer to Table 3-2.

Figure 3-3 shows how the first two components are linked and then moves to the interpretation phase of the assessment.

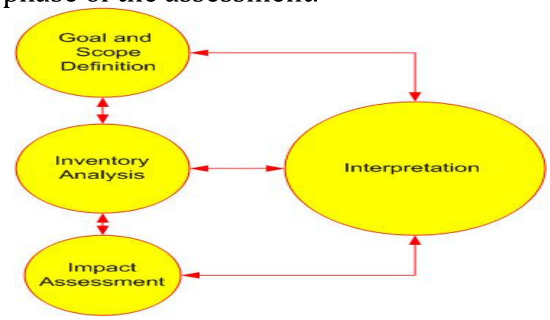

Figure 3-3: Life cycle assessment overview (Anon., 1998)

The LCA forms an integral part of ISO 14000(Reuter, 1998). LCA methodology is still being developed (Burgess and Brennan, 2001b) with a number of differing variations in existence. The most widely accepted is the Society of Environment Toxicology and Chemistry (SETAC, 1993) guidelines which defined an LCA as being comprised of: a life cycle inventory, a life cycle impact analysis and a life cycle improvement analysis. LCAs, in turn, adhere to strict standards laid down in ISO standards of the 14,000XX family series (Niederl-Schmidinger and Narodoslawsky, 2008) including ISO 14040, 14041, 14042, 4043,14047,14048, and 14049 framework for LCA includes, definition of the goal and scope, LCI, LCIA, interpretation and reporting. The main difference between the SETAC and the ISO versions are in the interpretation phase with the ISO tends to use more sensitivity analysis (Burgess and Brennan, 2001b, 2001a). This literature review has found many examples where an LCA has been performed on products. (Roberts, 2003) studied Aluminium Die Casting (Abrahamsson and Babazadeh, 1998) an LCA on silicon and gallium arsenide transistors, finding the LCA process was able to show that what appeared to be less environmentally friendly was actually better when looked at through the whole life cycle (the gallium arsenide).

Sweatman and Simon (1996) conducted an LCA on an Electrolux vacuum cleaner with the objective of not only discovering the environmental impact of this product, but also comparing LCA tools (software) for use in this analysis. It was found that (SimaPro) software can be justified if an in depth study is required but the cheaper software (Eco-Indicator 95) is suitable for a designer attempting to discover environmentally-friendly material. Burgess and Brennan (2001a) studied desulphurisation of gas oil. Other LCA studies found include a telephone, automobile materials and kerbside waste recycling. No LCA literature was found relating to conceptual sustainability management of engineering technology. The literature has found an explicit examples in the chemical industry and it is this industry which seems to use LCA process the most and in the most detail as part of the operating environment.

LCA characteristics	Brief explanation
Based on non-mandatory, international standards	LCA Standards are part of the ISO 14000 Environmental Management Systems series The ISO framework for LCA (ISO 14040:2006; ISO 14044:2006)
Uses a holistic approach	Covers the entire life cycle of the product, process or service
Has clearly defined system boundaries	The system boundaries define what is included or excluded in the study. All assumptions regarding the position of the boundaries should be clearly stated and justified.
Uses process models	Process models describe the key elements of the physical systems being investigated and their relationships
Transparent	Information should be presented in an open, comprehensive and understandable fashion so that the logic of methods used can be readily followed
Flexible	Can be used for different purposes eg. at the design stage, across the entire life cycle, to compare different products/processes and environmental labelling
Takes an iterative, integral approach to the data	Enables the process model to cope with multiple operations and activities eg. resource use, solid and liquid emissions to air, water and soil
Has a defined functional unit	A reference unit that allows comparisons to be made within the model and between models
Decision support tool which should not be used in isolation	Provides a strategic framework to support the decision-making process. Quantifies the environmental data, but doesn't determine the social, environmental or health effects
Uses both subjective and scientific based decisions	Some LCA phases are very subjective eg. the selection of impact categories and indicators, whereas others have a stronger scientific basis eg. the collection and quantification of specific data.
3 different levels of LCA	1. Conceptual 2. Simplified 3. Detailed
A detailed LCA is composed of 4 distinct phases	Phase 1 Goal and scope definition Phase 2 Life Cycle Inventory Analysis (LCI) Phase 3 Life Cycle Impact Assessment (LCIA) Phase 4 Interpretation of results
Can be very demanding and expensive	Often requires a rigorous collection and analysis of data which can be very time consuming and expensive

Table 3-2 : Contains a brief summary of the main characteristics of LCA adapted from (Roberts, 2003; Wiegard, 2001)

3.4.2 Cost-benefit analysis (CBA)

Cost-benefit analysis (CBA) is one of the available techniques used in environmental decision-making procedures, which measures the (un)sustainability of organizational activities, in particular, "the systematic estimate of all benefits and all costs of a contemplated course of action in comparison with alternative courses of action " (Seneca and Tausig, 1984). The CBA factors are all estimated in a common measure of 'money' to enable a direct comparison of , where costs are subtracted and benefits are added. the final decision is made based on the resulting net value, either positive or negative,. Indeed, the application of such efficiency criterion is considered to be fundamental for public decision-making, concerning public facility investments, development projects, environmental regulations, etc., by illuminating the advantages and disadvantages of the project and other possible alternatives, given the budget constraint.[1)] According to the policy discussion paper by (Arrow et al., 1995), examining the role of CBA in environment, health, and safety regulations, CBA not only informs about the allocation of scarce resources to be put to the greatest social good, but also about the amount of optimal regulation, i.e. control until the incremental benefits are just offset by the incremental costs, despite the inherent difficulty of measurement and the concern about fairness (Omura, 2004).

Bebbingtona et al.(2007) write that cost–benefit analysis has been promoted as a democracy enhancing technology. for example, Sunstein (2002), argued that CBA forces decision makers into conversations with objective data, that it makes decision-making more transparent, prevents undue pressure from interest groups, and increases accountability. Policymakers and practitioners have promoted CBA as a clarification and rationalization tool for social choices and building consensus (Corner House, 1999). Consequently, the opposition camp to this theory (Ackerman and Heinzerling, 2002; McGarity and Shapiro, 1996; Sinden, 2004) had provided a valid critique of these claims from both academics and practitioners with a broad interest ranging across a wide array of disciplines most notable claims were CBA flattens our most profound emotions, beliefs, and values into the dull grey of dollars and cents; it produces hopelessly indeterminate results; it clouds transparency and undermines public participation by giving controversial and uncertain predictions a false patina of scientific accuracy and objectivity.

3.4.3 Environmental impact assessment

An environmental impact assessment is an interdisciplinary planning instrument with the capacity to anticipate, predict the occurrence, plan, and manage the consequences of the design phases of the development. It also functions as a management tool to minimise potential negative impacts. The EIA forms an integral part of the project design process. Where the environmental evaluations of various design alternatives can be assessed against different trade-offs. As a result of EIA potentially negative impacts can often be avoided, without compromising the real cost of the project. Conversely, positive environmental outcomes associated with the project can be enhanced. This EIA process involves several key stages listed in Figure 3-4.

Scoping	To identify the issues and impacts that are likely to be important and refine the terms of reference for the EIA
Examination of Alternatives	To establish an environmentally-sound preferred option for achieving the objectives
Establishment of the Environmental Baseline	For the bio-physical, social and economic aspects of the environment to establish prevailing conditions prior to development
Impact Analysis	To identify and predict the likely environmental, social and other related effects of projects
Mitigation and Impact Management	To establish the measures that are necessary to avoid, minimise or offset predicted adverse impacts and, where appropriate, to incorporate these into an environmental management plan (EMP)
Evaluation of Significance	To establish the magnitude and acceptability of residual impacts that cannot diminish completely)
Preparation of the Environmental Impact Statement	To clearly document the impacts of the proposal, significance of effects.

Figure 3-4 EIA process key elements (Demidovaa and Cherp, 2005; Senecal et al., 1999; Shepard, 2006)

3.4.4 Triple bottom line

The "bottom line" is a metaphor often attributed to John Elkington, a co-founder and chair of SustainAbility LTD, UK, www.sustainability.com a sustainable business consultancy (Elkington, 2004) arising from within the business lexicon that confers the ability to capture, in a unique representation (a number), the effect of a multitude of separate actions (transactions) by systematically representing these actions using a common metric and summing the contributions (benefits) and detriments (costs). TBL is a business accounting tool; the quintessential symbol of the bottom line is the net income (earnings) reported on the financial statements of publicly held corporations. As a framework for organizations to translate the concept of Sustainable Development (Bruntland, 1987) into the operation of organizations, TBL and Corporate Social Responsibility programs are essentially the same. However, the TBL programs focus only on accounting and reporting (Brown et al., 2006). The following section presents an examination and discussion of the pros and cons of a selected number of non qualitative indicators.

3.4.5 Pressure state response

The OECD Core Set of Indicators for Environmental Performance Reviews reported the first mention of the Pressure-State-Response framework for the development of indicators (OECD, 1993). The feedback loop to pressures through human activities", this process is shown in Figure 3-5. Accordingly, in the PSR framework, there are three types of indicators:

i) Environmental pressures;
ii) Environmental state and
iii) Societal responses.

The Pressure-State-Response framework is based on a concept of causality: human activities exert pressures on the environment and change its quality and the quantity of natural resources "state". Society responds to these changes through environmental, general economic and sectoral policies "societal response"(OECD, 1994).

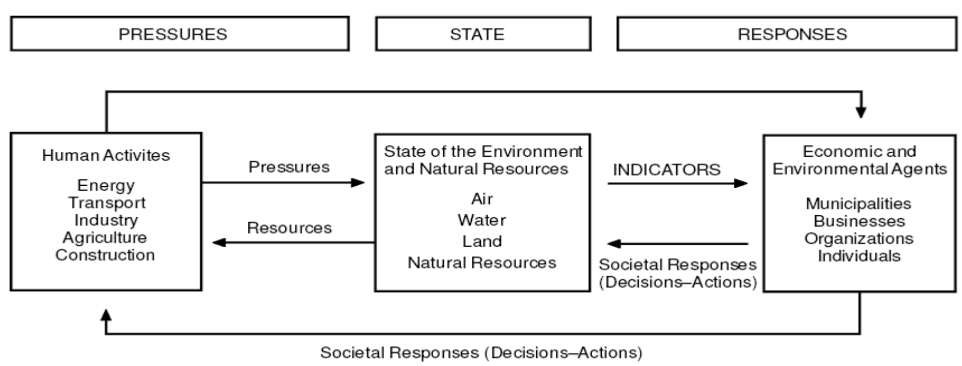

Figure 3-5: Pressure–state–response model (Guy and Charles, 1998)

The PSR limitations are summarized as follows;

- This is linear model environmental interaction is not
- Overlap in indicators pressure and state.
- Users must define forty indicators for each parameter

- Interlinkages in the model would be difficult to measure for indicators.

3.4.6 World Bank measure of the wealth of nations

In 1995, the World Bank published a report entitled "Measuring the Wealth of Nations", which determined the dollar value of natural capital, manmade capital and human capital for 192 countries. This is based on the concept of "genuine saving" which is defined as,

> "the true saving of a nation after depreciation and depletion of produced assets and natural resources, investments in human capital, and the value of global damages from carbon emissions" (Kaly et al., 2003).

"Since genuine savings is an accounting tool a negative net outcome of must lead eventually to declining well-being" (Hamilton and Clemens, 1997, 1999). The inherent limitations are as follows;

- Wealth is measured in monetary value
- Economic growth is highest priority

We acknowledge economic growth as important especially for developing nations however; economic growth is only one of the sustainability dimensions.

3.4.7 United Nations Commission on sustainable

The UNCSD published "Indicators of Sustainable Development: Framework and Methodologies" in (1996) and it was later updated in 1998. The frame work included a list of 140 indicators. Indicators were arranged under four classes:

- Social
- Economic
- Environmental and
- Institutional

3.4.8 Sustainable indices in the business world

The Dow Jones Sustainability World Indexes (DJSI) was created in 1999 the composite index was constructed by selecting the leading 10% of sustainability firms (which number more than 300) in the Dow Jones Global Index, which covers 59 industries over 34 countries (Hoti et al., 2005).

The DJSI composite calculation is offered in four specialised subset indexes, which exclude companies that generate revenue from (1) tobacco, (2) gambling, (3) armaments or firearms, and (4) alcohol. Holt et al. (2004) reviewed the Dow Jones Sustainability Index (DJSI), Ethibel, FTSE4Good, Domini 400 Social Index and Vanguard Calvert Social Index Fund, and Corporate Governance Quotient (CGQ) to identify similarities and differences across indices and attempted to determine the best approach to measuring sustainability. Table 3-3 represents a summary of the drivers used by each index in their evaluations. Hoti reported that whilst organizations were attempting to measure sustainability, it was discovered that very few actually translated their efforts into a standard metric, across the indices reviewed, and found little uniformity. Even though the indexes measure as the same dimensions environmental- and social-sustainable practices, they did not employ matching drivers.

	DJSI	Ethibel	FTSE4Good	Domini400	Calvert	CGQ
Economic						
Customer Relationship Management	red	black				
Scorecards/strategic planning	red					
Product quality/future value		black		green		
Environmental						
Presence of Environmental Policy	red	black	orange		purple	
Environmental Reporting	red	black	orange			
Measurement of Company Impacts	red		orange	green	purple	
Measurement of Product Impacts		black			purple	
Environmental management systems		black	orange			
Production initiatives		black		green		
Monitoring of suppliers	red	black				
Employee training					purple	
Social - Internal						
Equal Opportunities and Diversity	red	black	orange	green	purple	
Human Capital Development	red	black	orange	green		
Employee participation	pink			green		
Health & Safety of workers	red		orange		purple	
Employee Relations	red	black	orange	green	purple	
Social - External						
Stakeholder Consultation	red	black	orange	light green		
Corporate Citizenship/Philanthopy	red	black	yellow	green	purple	
Social Reporting	red		yellow			
Product Safety & Social Impact				green	purple	
Human Rights Policy & Monitoring	pink	black	orange	light green	light purple	
Human Rights Impact Assessment			orange			
Indigenous Peoples' Rights			orange		purple	
Supplier monitoring	red	black				
Corporate Governance						
Board composition	red	grey			purple	blue
Audit Issues	red					blue
Executive Compensation & ownership						blue
Governance & Ethics	red	black	orange		purple	
Investor Relations	red					
Risk & Crisis Management	red					

Table 3-3: Streamlined categories to evaluate drivers across 5 indices (Hoti et al., 2005)

3.4.9 The 7QS assessment framework

Tahlan (2004) reported on the Mining Minerals and Sustainable Development (MMSD) project. Essentially the assessment frame work was developed by working group that consisted of 35 individuals, representing different interests

> "and charged them with developing a set of practical principles, criteria and/or indicators that could be used to guide or test mining/minerals activities in terms of their compatibility with concepts of sustainability" (Tahltan, 2004).

Figure 3-6: Assessing for sustainability (Tahltan, 2004)

The mining mineral for sustainable development group developed Seven Questions to Sustainability (7QS) Assessment Framework. 7QS states a theme of practical sustainability in a way on people on the ground find it meaningful to the explorer, mine manager, mill superintendent, community leader or public interest group. The framework begins with seven questions falling within a hierarchy of objectives, indicators and specific metrics. The starting point for assessment of progress towards sustainable outcomes is provided by an "ideal answer" to the initial question. In this fashion, a single, initial motivating question—is the net contribution to sustainability positive or negative over the long term of the proposal/project. In this way the results cascade into progressively more detailed elements which can be tailored to the project or operation being assessed. The questions are illustrated in Figure 3-6.

3.4.10 Environmental Sustainability Index and Wellbeing Index

The Environmental Sustainability Index is a composite index for measuring sustainability; it originated in 2005Davos, Switzerland, at the annual meeting of the World Economic Forum. It mainly derived from socioeconomic, environmental, and institutional indicators derived from with 68 indicators for 148 countries (Esty, 2002; WEF, 2002). Parris and Kates (2003) conducted an excellent review of ESI, these indicators were aggregated into five components and twenty core indicators:

- environmental systems reducing environmental stresses
- reducing human vulnerability
- social and institutional capacity and
- global stewardship

The extreme of the Environmental Sustainability Index agrees well with the Wellbeing Index. However, Hungary was ranked eleventh, Brazil twentieth, and the United States forty fifth out of 148 countries, representing significantly different results from the Wellbeing Index (Parris and Kates, 2003).

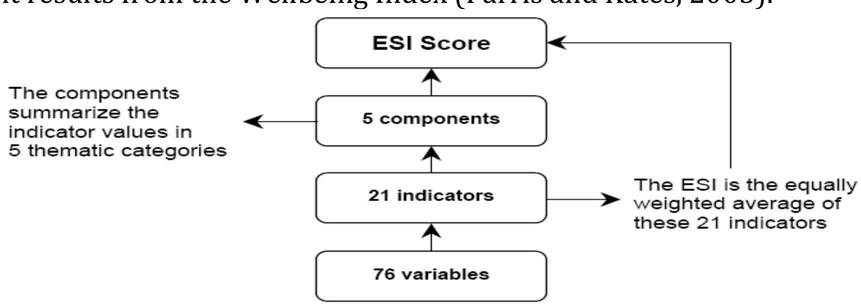

Figure 3-7: Constructing ESI score

3.4.11 Victorian's weekly greenhouse indicator

In 2007 Victorians were offered with a web tool to regularly track their ongoing contributions to climate change via monitoring their carbon emissions, with the launch of a world-first weekly indicator showing the state's key sources of greenhouse gas emissions. The indicator will allow Victorians to see how much their use of coal-fired electricity, petroleum and natural gas is adding to the state's growing greenhouse emissions (Minchin, 2007).

3.4.12 Barometer of sustainability

Originally attributed to Prescott-Allen (1997) consists aggregate indicator of sustainability. The indicator consists of two well-being axes

1. Ecosystem and
2. Human.

The judgment of overall sustainability is based on the axis with the lower score (with the worst performance) which at the same time covers environmental, social and economic components of sustainability, keeping the ecosystem and the human system separate to determine their individual sustainability. Graphing the results indicates the range of conditions from good to bad. The perceived advantages of this method are easy use of calculations, visual representation of results. The main benefit of the barometer is its core ability to separate trade-offs between human and ecosystem well-being, this basis is assumed from the starting point of the barometer which regards that ecosystem and human well-being are equally important. The barometer subjectivity is considered as the major limitation, recognized (Hardi and Barg, 1997; Bossel, 1999; Guijt and Moiseev, 2001). Overall, the process is time consuming; data availability may be a problem depending on the level of assessment allowed to the interested parties to define their own criteria for sustainability.

3.4.13 Ecological footprint

The Ecological Footprint is an indirect way to measure sustainability it accounts the impact of inhabitants on nature.

> "each human activity needs land capital and produces waste flows later converted in nature" (Wackernagel, 1997; Wackernagel and Rees, 1996).

It calculates the carrying capacity for a population by measuring the total amount of land required to support consumption of food, water, energy and waste generation of a population. The advantages are a single figure indicator that is easy to understand the key limitation is it requires a large amount of data, information is lost due to aggregation; does not include all resource use (i.e. water, marine resources and waste); does not cover social or equity aspects(Rees and Wackernagel, 1994; Wackernagel, 1993).

3.5 Engineering specific programmes

3.5.1 Sustainability Assessment Model (SAM)

The Sustainability Assessment Model (SAM), measuring operational sustainability, is a tool used for modelling and evaluating the sustainable development performance of projects, organisations and industry sectors. It originated in 1998 at BP (British Petroleum), in conjunction with the University of Aberdeen and Genesis Oil and Gas Consultants for use by industries to assess the sustainability of project developments (Baxter et al., 2002), It assesses the positive and negative impacts of projects through their full life cycle, taking into account externalities.

This method is constructed as a full cost accounting techniques (Bebbington et al., 2001) which quantify the internal and external costs and benefits related to particular actions, impacts (positive and negative) are dealt with in four categories: economic, resource usage, environmental and social. It starts by assessing the capital at the start of the project, impacts caused, and then finally, the capital at the end of the project, under these categories:

- Full life cycle analysis social environmental and economic resource -
- Exploration, design, installation & construction commissioning,

- Production,
- De-commissioning.

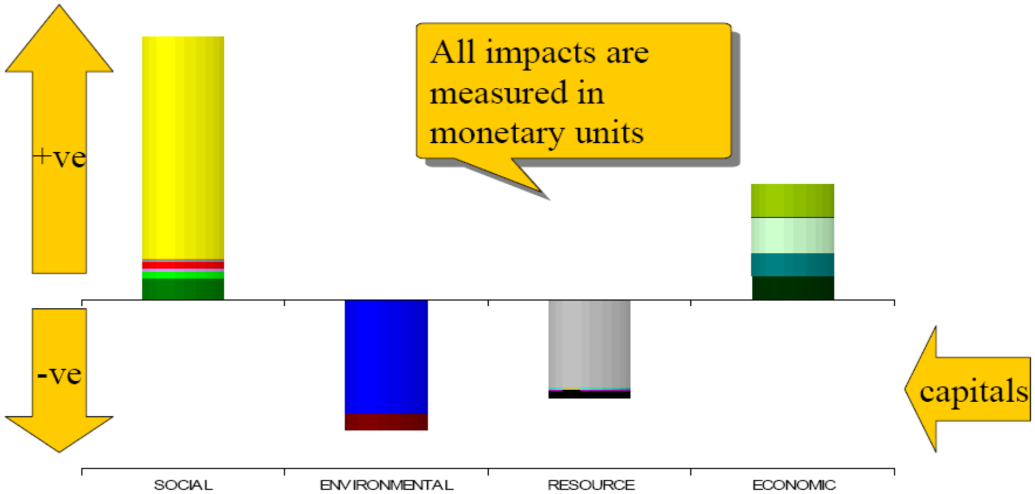

Figure 3-8: The SAM signature (Baxter et al., 2004)

The results of the analysis are presented in graphs (using a positive and negative axis) to indicate their "signature" (see Figure 3-8). All impacts are measured in monetary units, and provide an index which 'measures' the sustainability of a project. The method is likely to be limited by the availability of quantitative data.

3.5.2 Chemical Engineering sustainability metrics

Globally there are two main professional bodies for chemical engineers, the Institution of Chemical Engineers (IChemE) is a UK-based global institution with 27000 members (IChemE, 2007) and The American Institute of Chemical Engineers (AIChE) has 40000 members (AIChE, 2007).

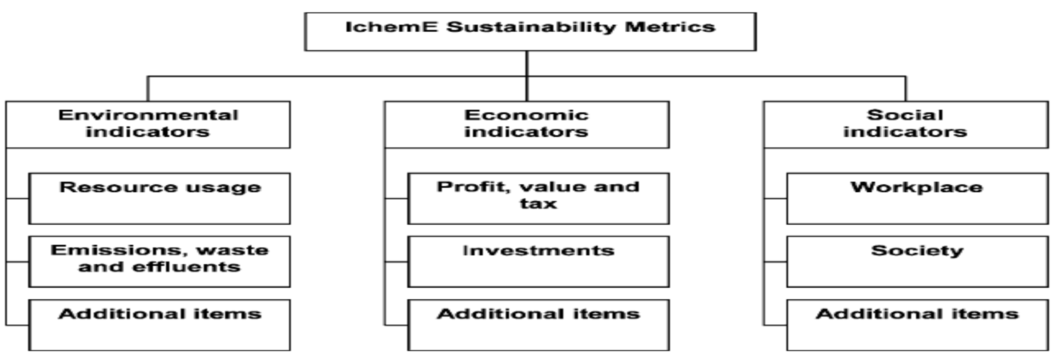

Figure 3-9: The Institute of Chemical Engineers sustainability metrics(Labuschagne, 2003)

The most prominent of sustainability in the chemical engineering industry is the IChemE's sustainability metrics and the AIChE Sustainability Index (SI), both systems have the London Communiqué of 1997 as their basis their encapsulating sustainable development .This statement was signed by the leaders of 18 chemical engineering societies throughout the world, and later in 2001 at the Sixth World Congress of Chemical Engineering where the Melbourne communiqué was founded represented by twenty organisations. IChemE (2002) published a set of sustainability indicators to measure the sustainability of operations within the process industry. In addition IChemE provides standard reporting forms and conversion tables. This framework is intricate and impact oriented (Tallis, 2002).

However, the framework strongly favours environmental aspects, as well as quantifiable indicators that may not be practical in all operational practices, e.g. in the early phases of a project's life cycle (Labuschagne, 2003). Consequently the content of the 7th World Congress of Chemical Engineering, held in Glasgow in 2005, effectively endorsed the Melbourne communiqué.

l. Environmental	Resources	Environmental - resources Energy use Material use Water use Land use
	Impacts	Acidification Global warming Human health Ozone depletion Photochemical ozone Wastes - hazardous, non-hazardous Ecological health
2. Economic		Value added per unit value of sales Value added per direct employee R&D expenditure as % sales
3. Social		Benefits as percentage of payroll expense Promotion rate Income and benefit ratio (top l0%/bottom l0%) Lost time accident frequency Expenditure on illness and accident Prevention/payroll expense Number of complaints per unit value added

Table 3-4: Brief summary of IChemE Indicators

Finally the ICheme metrics are presented in three groups: social, economic, environmental, and indicators as shown in Figure 3-9 . It consisted of 50 indicators classified into class examples listed in Table 3-4. On closer examination, the indicators reflect the triple-bottom-line paradigm. Most of the economic and societal metrics are not reported per output basis and therefore do not constitute measurements of eco-efficiency. The striking limitation of the ICheme indicators was reported by Martins (2007) he describe the metric as being applicable to a specific process or to the entire corporation, However, the list is too long and unwieldy for systematic application and lacks temporal and spatial factors (Diniz da Costa and Pagan, 2003). Furthermore, Mclellan (2004) compare the metric as similar to life cycle analysis (LCA) methods which determine overall process, cradle to grave analysis. This allows a process to be monitored for sustainability improvements, or to compare different process options, but does not include specific local parameters. This lack of specificity may reduce the potential of this technique to assess different locality options. Also it can said that ICheme metric is largely based on (Azapagic and Perdan, 2000) work on indicators which presents its own limitations, as it is has a strong affinity to the triple-bottom-line.

3.5.3 The Institution of Engineers, Australia

In 1994, the Institution of Engineers Australia adopted its first policy on sustainability and in 1997, it published engineering frameworks for sustainability (Institution of Engineers Australia, 1997), Engineering

Frameworks for Sustainability geared towards sustainable engineering practice. This framework consisted of 6 chapters, a green building guide, transport, water, energy efficiency and chemicals management. It also included the Newcastle declaration on World Environment Day, 5th of June 1997, acknowledging the Rio Earth summit. The basis theory of the framework referred to LCA, CP, CER and risk management criteria.

3.5.4 Green engineering

Green engineering (Anastas et al., 2000) focuses on how to achieve sustainability through science and technology within the context and perspective of environmental, economic and social benefit (Ehrenfeld, 1997; Fiksel, 1998; Skerlos, 2001). Anastas, (2003) described the role of engineers and designers on all scales-molecular, products, processes, and systems as central and essential in determining what tomorrow will look like. The Principles (referred to in Table 3-5), provide a outline to engage in benevolent factors whilst designing new: material, product, process, or system. According to Anastas, (2003), Anastas and Zimmerman (2003) whom described the twelve principles of Green Engineering as a tool that allows designers to consider fundamental factors at the earliest stages as they are designing a material, product, process, building or a system. The principles are designed to be considered as a collection of parameters in a complex system that needs to be optimized, including taking advantage of synergies and recognizing trade-offs. The application and emphasis of individual principles will be largely contextually.

Principle 1	Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.
Principle 2	It is better to prevent waste than to treat or clean up waste after it is formed.
Principle 3	Separation and purification operations should be designed to minimize energy consumption and materials use.
Principle 4	Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
Principle 5	Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
Principle 6	Embedded entropy and complexity must be viewed as an investment when making design choices on recycle reuse, or beneficial disposition.
Principle 7	Targeted durability, not immortality, should be a design goal.
Principle 8	Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
Principle 9	Material diversity in multi-component products should be minimized to promote disassembly and value retention.
Principle 10	Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
Principle 11	Products, processes, and systems should be designed for performance in a commercial "afterlife".
Principle 12	Material and energy inputs should be renewable rather than depleting.

Table 3-5: The 12 Principles of Green Engineering extracted from (Anastas, 2003; Anastas and Zimmerman, 2003)

3.5.5 Material flow accounting or analysis

MFA is a form of material balance; it studies the flows, feedbacks, and delays. Where raw materials, such as water and air are extracted as inputs used in products and finally returned as waste (Halberg et al., 2006), it is defined as the

> "quantitative description of inputs and outputs material of process" (Bringezu and Moriguchi, 2002).

MFA is typically applied to determine resource utilization, or waste approximation so that recycling rates could be estimated and activities could be implemented to improve waste recovery and recycling could be planned (Melo, 1999; Van Schaik and Reuter, 2004; Verhoef et al., 2004). It applies the use of residence time theory (Van Schaik and Reuter, 2004) to locate where material is lost.

3.5.6 Cleaner production (CP)

CP is a preventative environmental management strategy which emerged in the USA; it is defined as a continuous improvement in Eco-Efficiency through the prevention of the generation of wastes and emissions. It is also framework for reducing the environmental impacts through the waste reduction, reuse or recycling techniques (Ku-Pineda and Tan, 2006).

Cleaner Production Guides	Life Cycle Costing
Corporate Environmental Reporting	Life Cycle Design
Design-for-Environment	Life Cycle Engineering
Design for Disassembly	Life Cycle Management
Eco-auditing	Life Cycle Value Assessment
Eco-compass	Pollution Prevention
Eco-Efficiency	Product Stewardship
Eco-industry Parks	Responsible Care
Eco-profiling	Social Justice Indicators
Environmental Auditing	ISO 14000 Standards and Various
Environmental Management Systems	National Environmental Standards
Environmental Performance Evaluation	Supply Chain Management
Environmental Performance Indicators	The Natural Step System Conditions
Life Cycle Assessment	

Table 3-6: Environmental management tools (Young et al., 2001)

Its global presence has been assisted by promotion from, United Nations Environment Program, the European Union and many national governments, including Australia. The CP term is often used interchangeably with Eco-Efficiency (Pagan et al., 1999) Pollution Prevention, Waste Minimisation, Green Productivity, and although both concepts are complementary (Van Berkel, 2000) and mutually reinforcing (UNEP and WBCSD, 1998; UNEP, 1997; WBCSD, 1996). There are slight differences Eco-Efficiency is strategic evaluation of value creation and CP on the operational evaluation (Van Berkel, 2000). The limitations of some CP tools such as an Environmental Management System (EMS) which require targets within the system. These targets can be internally based on the environmental review for detailed lists some of the available tools please refer to Table 3-6.

Furthermore, additional tools with environmental awareness commonality, such as clean technology, design for the environment; factor ten, environmental management systems, extended producer responsibility, industry ecology, and life cycle assessment create additional confusion (Petrus, 2006). Figure 3-10 illustrates the level of overlap and therefore, the potential confusion for users between the choices of tools.

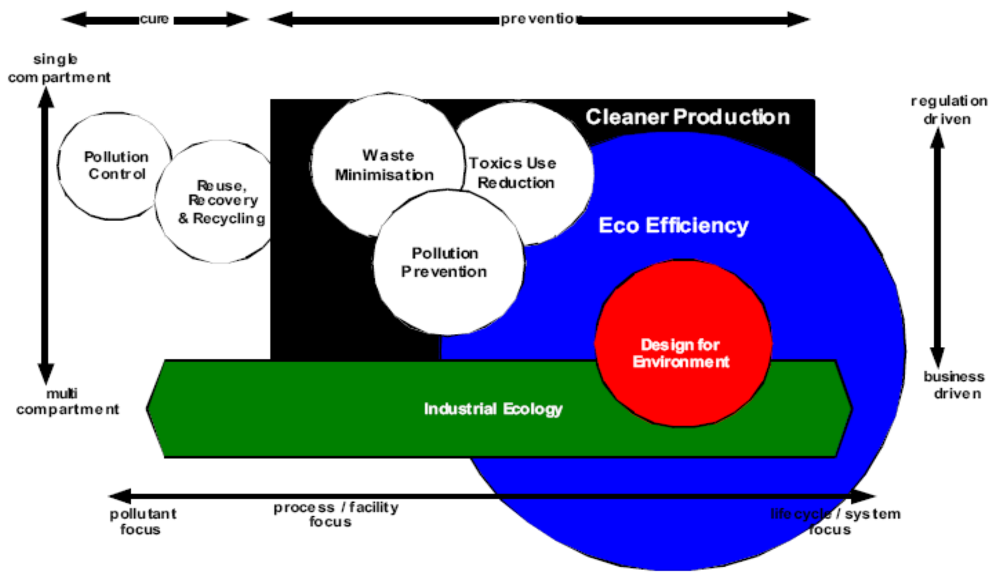

Figure 3-10: Environmental improvements concepts (Van Berkel, 2000)

3.5.7 The sustainability process index

The SPI was developed by (Narodoslawsky and Krotscheck, 2004) as a tool to evaluate industrial processes. It is primarily based on a life-cycle approach, it uses mass and energy balances of the processes (Narodoslawsky and Krotscheck, 2000).

> "The references used are the natural concentrations of substances in the compartments atmosphere, groundwater and soil. The factor 'area' was chosen as the basic unit for the computation of the SPI for the reason that, in a sustainable economy, the only real input that can be utilized in the long-term is solar energy. Its utilization per se is bound to the surface area. Furthermore, area is a limited resource in a sustainable economy because the surface of our planet is finite" (Krotscheck and Narodoslawsky, 1996).

This model is based on functionality of area both as a recipient of solar energy and as a production. The measurement is deduced by calculating the quantity and the quality of the energy and mass flow. For example a any process requiring more area for the same product or service are less sustainable. The total area for embedding a certain process into the environment is given by:

$$A_{tot} = A_R + A_E + A_I + A_S + A_P \quad m^2 \tag{3.1}$$

Where,

A_R = the area requirement to produce raw materials,
A_E = the area necessary to provide process energy,
A_I = the area to provide the installations for the process,
A_S = the area required for the staff, and
A_P = the area to accommodate products and by-products.

The reference period for all of these areas is computed as one year basis. In the discussion that follows, all components that will be in use for a time more than the reference period will be discounted to consider service life.

$$a_{tot} = \frac{A_{tot}}{N_p} \tag{3.2}$$

Where,

> $N_{P=}$ *specifies the number of goods or services produced by the process in question, e.g. the number of kWh produced by a specific energy system.*
> a_{in} *= the area at disposal for every person (in a given region).*

$$SPI = \frac{a_{tot}}{a_{in}} \tag{3.3}$$

3.5.8 Exergy

Exergy, a term invented by (Rant, 1956), exergy is work, it combines the first and second laws of thermodynamics in a manner analogous to Gibbs energy and Helmholtz free energy. It is a measure of its usefulness or quality or potential to cause change (Rosen and Dincer, 2001) . it is represented in four forms: kinetic, potential, chemical and physical (i.e. pressure–volume and heat exchange type work). The reason exergy was selected in an engineering assessment since it has the ability to be applied in all industrial processes embodied in thermodynamic transformation i.e. energetic flows "A general relationship can be drawn between exergy and the material life cycle wherein high exergy (low entropy) resources are extracted from the environment, refined by the economy and returned to the environment as low exergy (high entropy) waste"(Seager and Theis, 2002).

3.5.9 Emergy

Emergy analysis ''m'' is an environmental accounting method, Ulgiati and Brown (2002) defined it as "the amount of energy of one form (usually solar) that is required, directly or indirectly, to provide a given flow or storage of energy or matter" The unit is solar emergy joule (sej). Emergy is considered the available solar energy, in order to make a service or product (Odum, 1996b; Odum and Odum, 2001). It measures quality differences between forms of resources and energy. it has its roots and conceptual basis in the thermodynamic language of open systems (Odum,1971; Odum and Odum,1981; Odum,1983; Odum,1986(Brown and Buranakarn, 2003). Evolution of the theory over the past 30 years was documented by (Odum, 1996a) in Environmental Accounting and in the volume edited by Hall, entitled Maximum Power (Odum, 1995). Emergy analysis quantifies the relationships between human-made systems and the natural biosphere (Pulselli et al., 2007). The emergy analysis standardises value to products and services by converting them into equivalents of one form of energy, that being, solar energy, which is used as the common denominator through which different types of resources, either energy or matter, can be measured and compared to each other (Pulselli et al., 2007).

3.6 International standards

Standards for the implementation of LCA and EMS management tools are governed by the International Standards Organisation (ISO). Environmental Management Systems are specified in the ISO14000 series2, particularly (ISO14001, 1996; ISO14004, 1996) while LCA are described in the (ISO14040, 1997) series. ISO14001, Environmental Management systems specification with guidance for use, describes a documented control system for the environmental management of a company which may be implemented and then audited by authorised external agents leading to official 'accreditation'; an acknowledgement that the company has met the requirements of the standard.

The standards associated with LCA describe the general minimum requirements for the studies, for example which elements they should contain, how they should be documented, peer reviewed and reported.

IER can be used as the first step in a formal approach to environmental management, and it is compatible with the (AS/NZS ISO14040, 1998). A Framework for the IER Handbook has been prepared as a stand-alone document, i.e. it does not require reference to other Standards or Handbooks; rather, it consists of the four steps detailed in Figure 3-11.

(1) Identification of environmental aspects
(2) Identification of applicable legal and other environmental requirements
(3) Examination of existing environmental management practices, procedures and activities (including procurement and contracting)
(4) Evaluation of previous emergency situations and accidents
(5)

PLANNING	• Scope and objectives • Schedule • Safety and access • Budget • Roles, responsibilities, activities
INFORMATION REVIEW	Obtain and review information about the organization, site and operational criteria
INFORMATION COLLECTION	**Site visit** • Confirm information from the Information review • Obtain new information **Interviews and discussions** Verify, confirm and augment information and data from the Information Review and Site Visit
EVALUATION	Assess the information and data collected and evaluate against the appropriate criteria
REPORT / RECOMMENDATIONS	Summaries IER activities and findings

Figure 3-11: IER environmental management compatible with the AS/NZS ISO 14000

3.7 Sustainability assessment discussion

Increasingly, sustainability assessment is viewed as an important tool to aid in the shift towards sustainability (Pope et al., 2004).Sustainability assessment is used to describe a range of very different processes. There are also dissimilar terminologies which are used to refer to it, i.e. sustainability appraisal (Sheate, 2004), integrated sustainability appraisal (Eggenberger and Partidario, 2000), integrated impact assessment (Sheate, 2003), Furthermore, (Verheem, 2002) reports the aim of sustainability assessment is to "ensure that plans and activities make an optimal contribution to sustainable development. Hence, thus far in this chapter, I have reviewed the many evolving forms of sustainability assessment tools. Basically, the literature on sustainability assessment processes ranges from a variety of 'integrated assessment', derived from an environmental impact assessment (EIA) and an extended form of strategic and general environmental assessment (SEA) that incorporates social and economic considerations as well as environmental ones, reflecting a 'triple bottom line' (TBL) approach to sustainability. Many sustainability assessment systems documented in this chapter involve the use of qualitative techniques as a foundation used to gather data and quantitative methodologies that employ questionnaires and scaled responses. Hence, Table 3-7 lists the common Sustainability Assessment tools readily available. These can be categorized into two types as follows:

1. General laymen: sustainability assessment tools
2. Engineering specific programs: sustainability assessment tools

George (2001) recognised the important role of environmental, social and economic objectives within sustainability assessment decision-making process. Despite the persistent measurement tools ambiguities Parris and Kates (2003) described sustainability indicators to have had broad appeal and little specificity, we found indicators to be dominated by quantitative environmental, as well as equity indicators,. Similarly, advocates of sustainability assessment tools remain at odds on deciding what is to be measured and how to link technical parameters.

A number of researchers had proposed numerical schemes, comparisons in real world, or ideal cases however most of these schemes had failed to consider engineering related process and consequently failed to win public acceptance due to over complexity. Sustainability' Assessment in engineering firstly requires that the concept of sustainability is well-defined in terms of sustainability criteria against which the assessment is conducted. Chapter 2 of this thesis introduced this discussion by elaborating the general theme of sustainability definitions". Sustainability' Assessment in engineering needs to be proactive and not reactive, we need to learn from history, for example by analysing Figure 3-12 represents the environmental impact assessment, highlighting the differences in the approaches used where it is a choice between acceptable impact and adverse impact.

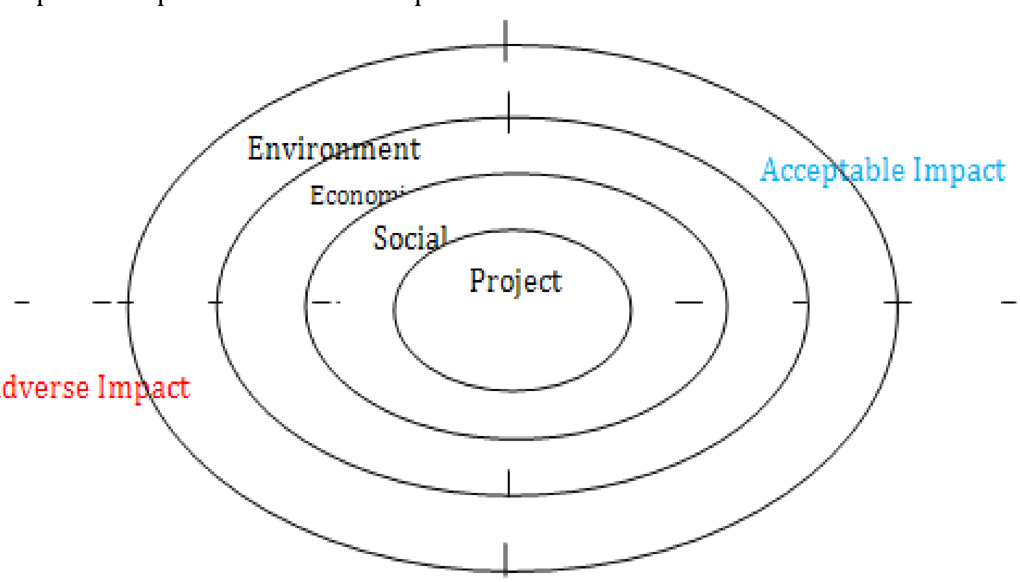

Figure 3-12: Reactive Assessment (Hasna, 2009c)

A proactive method represented by Strategic Assessment to ensure that triple bottom line impacts of a proposal are acceptable compared with baseline conditions. Figure 3-13 illustrates the spectrum where assessment is compared between more sustainable or less sustainable.

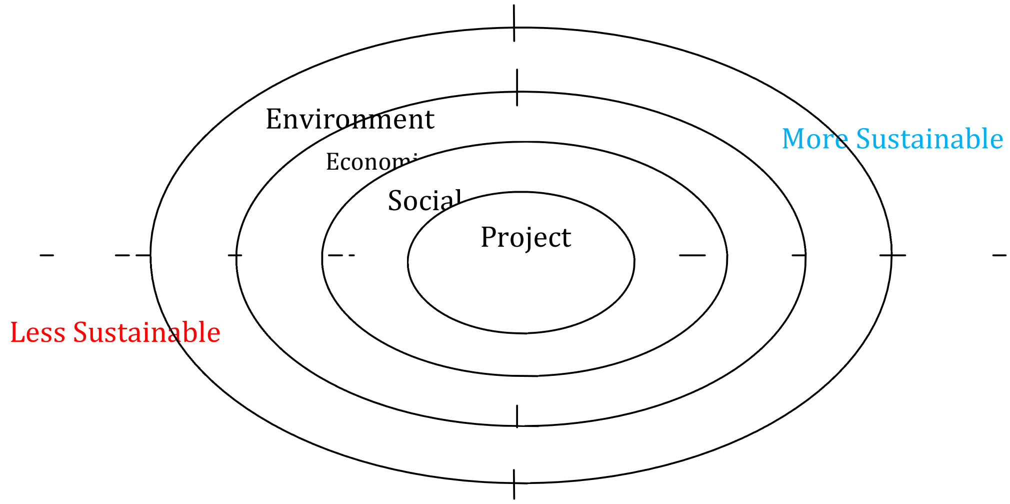

Figure 3-13: Proactive Assessment (Hasna, 2009c)(Hasna, 2009c)

In this chapter, I intended to stimulate debate about appropriate sustainability metrics and methodologies for engineering applications, by reviewing the various approaches described in the literature. For engineers and the engineering industry it's difficult to set goals when the metrics are not available to measure, this presents a confusing position as to how to deal with the vast number of assessments that exist. We need an effective tool for sustainability assessment, to expand across all levels of engineering decision-making, to existing practices across all sectors prevailing across policy and legislation, because all engineering decisions have the potential to impact on patterns of production and consumption; governance and settlement. Finally, the aim of this thesis is to generate a discussion on sustainability assessment for engineers and to encourage engineers to use the same language meaning and the same benchmarking standard for sustainability assessment; this is the basis of the proposal for a step-by-step process for sustainability assessment which is developed and discussed in both chapters Chapter 5 and Chapter 7.

General	Engineering
Barometer of Sustainability	Socio-ecological Indicators of Sustainability
Environmental Impact Assessment EIA	Sustainability Assessment by Fuzzy Evaluation (SAFE)
Ecologically Unsustainable Trade	Sustainability Footprint
Ecosystem Resilience	Systems Theory and Basic Orientors
The Natural Step	Waste Assimilation Capacity
Cost Benefit Analysis CBA	Waste Potential Entropy
dynamic hierarchical approach	Energy System Assessment
Contingent ranking	The 7QS Assessment Framework
Pressure state response (PSR)	Material flow accounting MFA
Environmental Pressures (EP)	Sustainability Assessment Model (SAM)
Environmental Space	The Institution of Chemical Engineers Sustainability Metrics,
World Bank measuring wealth of nations	Green engineering
Environmental Sustainability Index (ESI)	Cleaner production
Green Net National Product (NNP)	Sustainability Process Index (SPI)
Genuine Progress Indicator	Exergy
Genuine Savings	Ecological Footprint

Green Net National Product (NNP)	Life cycle analysis LCA,
Human Appropriation of Net Primary Productivity (HANPP)	The Institution of Engineer, Australia
Triple Bottom Line TBL	Material Unit Per Unit Service (MIPS)
Human Development Index (HDI)	Emergy Analysis
Environmental Sustainability Index and Wellbeing Index	Material and Energy Flow Analysis (MEFA)
I = PAT formula	RM Risk Management
Index of Social and Economic Welfare	Multi-Criteria Decision Making MCDM
Indicators for agro ecosystems	BRIDGES' Sustainability Framework
Level of Living Index	
Sustainable enterprise indices: Dow Jones Sustainability Indexes	
Maximum Sustainable Use (MSU)/ Abuse (MSA)	
Modelling World Resource Dynamics (World3 model)	
Natural Resource Availability	
Real Wages Resource Accounting Input-Output Models	
United nations CSD indicators	

Table 3-7: Sustainability Assessment in literature (Hasna, 2009c)

3.8 Critique of assessment tools

Considering the above review the central issue for engineers in the context of sustainable practices in engineering would be the plethora of sustainability definitions and assessment tools. A number of notable works had critiqued the limitations of these tools. For instance Hurley et al. (2008) articulated limitations of tools use to include the following;

(a) Lack of available data
(b) Difficult Public engagement
(c) Criteria weighting is subjective
(d) Vague Criteria
(e) Criteria evaluations

According to (Pediaditi et al., 2006) most tools that do exist focus on building performance and environmental issues during construction and thus fail to consider the site holistically across its lifecycle. Jha and Murthy (2006) found serious problems in respect to ESI methodology. In addition there are no tools capable of assessing the sustainability of a redevelopment project throughout its life-cycle (meaning from its conception and design to construction and its operation) (Pediaditi et al., 2005). Smythe and Isber (2003) found need for additional guidance and training in the analysis of cumulative and indirect effects and for more specific guidance on the appropriate level of analysis. Finally, in critiquing the assumptions inherent in the use of sustainability assessments in engineering, most current tools are general enough to cover various dimensions; recycling; waste prevention and reduction; pollution prevention; and life cycle costing in its daily practices. These broadly based challenges have shaped and influenced.

Finally there is no doubt about the need has been identified to develop a comprehensive measurement framework of sustainability assessment in engineering however the stalemate arrives by the limitations and shortcomings of these tools. Time and again tools purporting to enable or facilitate sustainability in engineering practices show a discrepancy in the issues they examine.

> "The scope of these tools has manifolds to include decision making, management, advocacy, participation, consensus building, research and analysis" (Parris and Kates, 2003).

Sustainability assessment needs to be relevant to gain preference by industry groups; to reveal at a glance how far (or near)? Whether sustainability is being approached or not? it needs to develop synergies, to produce robust measures, since existing tools use arbitrary scales and aggregates not grounded in theory. For example neither EIA nor CBA have standards associated with them, even though they represent long established and professionally accepted processes. Risk Management is backed by Australian/New Zealand (AS/NZ) standards (AS/NZS4360, 2004).

3.8.1 Discipline specific rating schemes

A large number of discipline specific rating schemes, techniques exist to perform sustainability appraisals. Whilst their names varied considerably the tools tended to be not general engineering schemes with a proactive sustainability tools, these are performance-based rating systems (environmental, social and economic criteria). With a few exceptions they are specific to trades, and furthermore, the rating schemes are:

- Not comprehensive
- Not global
- Not a total environmental solution

For example (e.g. rating schemes used in the built environment), The Australian Green Infrastructure Council (AGIC) Australian Sustainable Built Environment Council (ASBEC). These are specific to the building industry supported by local, state and federal government initiative, designed as initiatives primarily for the building industry. For example NABERS is the National Australian Built Environment Rating System is a national initiative managed by the NSW Department of Environment and Climate Change. It rates a building on the basis of its measured operational impacts on the environment, and provides a simple indication of how well you are managing these environmental impacts compared with your peers and neighbours.

3.9 Concluding remarks

This chapter presented a survey on sustainability metrics available nationally, internationally, and locally or is company focused, to understand the existing body of knowledge. It reported on 55 sustainability assessment tools. The large number of indicators is indicative of the perplexity surrounding of what is to be measured (Henderson, 1991). Thus, providing a prolific ground for fresh discussion and understanding on sustainability assessment. Each metric was briefly examined, as shown in Figure 3-14, but unfortunately there are many more which were not covered due to the space and scope limitation which prohibited further investigations in this direction. The review basis was: the indicator framework included a set of measurable indicators; addressed dimensions of sustainability, and has a wide focus, i.e. at a national, community or company level.

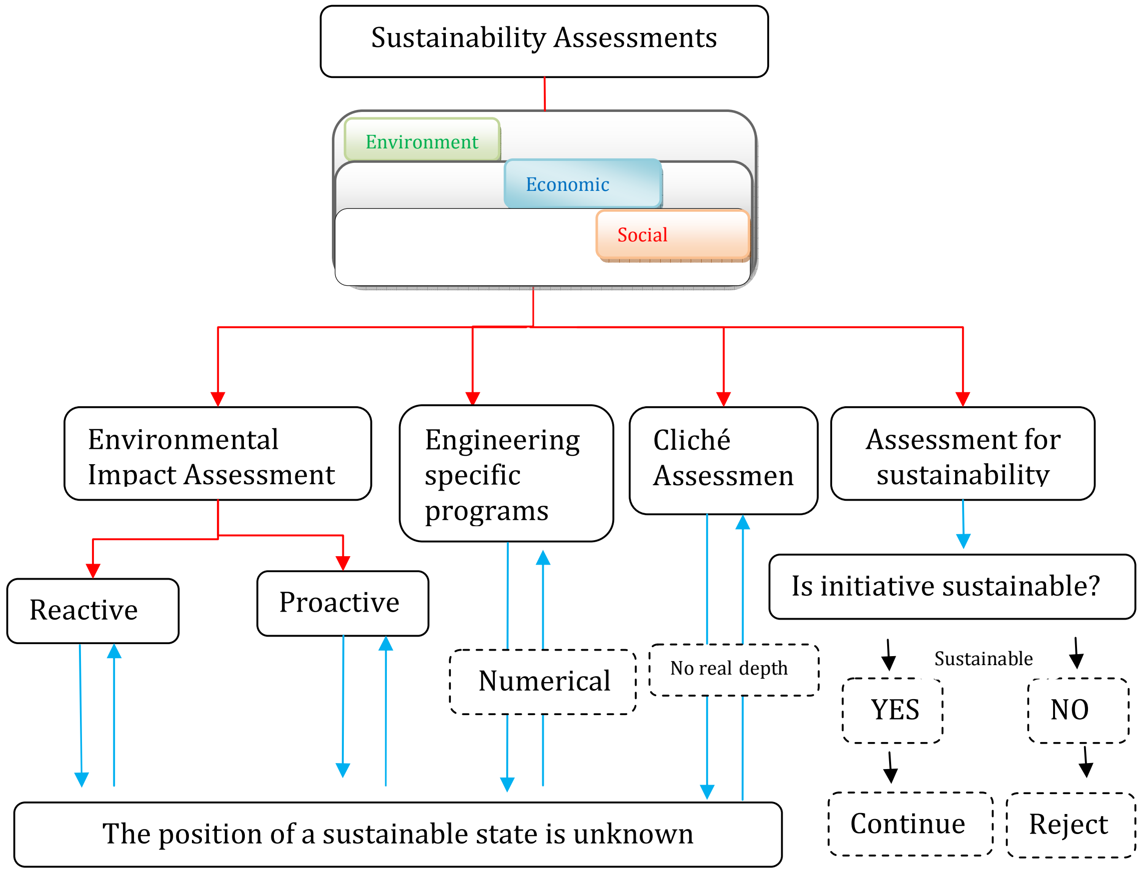

Figure 3-14: Sustainability assessment (Hasna, 2009c)

Product-only focused frameworks were not considered. However, in conclusion, the literature has demonstrated that the level of disclosure between protocols and criteria varies considerably. The critique of CBA and other metrics alike contains valuable lessons for sustainability decision processes, as it clarifies the over-reliance on monetization. In addition, the reviewed indices and metrics were vague, showed methodological disparity and provided little tangible metrics to evaluate. The primary concern of engineers is uniformity, consistency and organization of evaluating factors to quantify, which is one index of sustainability. The scientific validity of the methodologies is beyond the scope of this thesis to review in detail, particularly regarding the elaboration of indicators, data gathering, data processing, measurability and the scientific soundness of the concepts underlying the indicators. In summary, it has been suggested that to be effective and an instrument of change, 'assessment for sustainability' must be applied; within a structured framework (Jenkins et al., 2003); to propose a new initiative at all levels of decision-making (Noble, 2002); and to existing practices across all sectors. This position contributes to the line of this thesis' enquiry which promotes sustainability discussion in engineering; hence the selection of the proposed sustainability criteria for quantifying purposes, as outlined in Chapter 7, is consistent with the literature review findings.

Chapter 4. Natural Resources, The Profession and Sustainability

4.1 Outline

This chapter covers two central themes by reviewing the importance of natural resources and the engineering industry to the Australian economy with cursory review using case study analysis. Furthermore, engaging engineering with wider community in a global context the rationale behind this theory was demonstrated though case study analysis of energy efficiency In addition, this chapter pertains the changing nature of the engineering practice in contemporary society, dealing with issues like ethics, risk, and vicarious liability.

4.2 Background

In a global context this chapter begins by introducing the importance of engineering, industry and technology to the economy. It is no hidden secret that ICT and globalisation had changed the conduct of business in engineering. Innovation is the central issue in economic prosperity (Hargroves and Smith, 2005) Freeman and Soete (1997) argued that innovation is only accomplished in an economic sense.

> "Regions, nations and people can only prosper if the companies they host are successful. In order to be successful, companies need to be competitive. In an increasingly globalised world, with very strong competitors operating in the domestic, as well as the global market, companies must make additional efforts to strengthen their competitiveness" (Berger, 2005).

Innovations lie at the heart of technological competitiveness. Technological change is the driving force of economic growth. Hence, growth and competitiveness are influenced by the stock of human and natural capital.

> "International competitiveness is based on technological competitiveness and the ability to compete in delivery, while the influence of cost competitiveness is less important. Competitiveness can be seen as the outcome of a continuous process of innovation that enables firms to catch up and keep up as technology and the mode of competition change" (Fagerberg, 1988)

In the age of climate change industrialisation can be sustained only if the key players like engineering industry are able to develop competitive capabilities with sustainability. This concept has gained favour in a fertile ground, since society is becoming fast aware of the environmental and social impacts of economic activities.

"Awareness comes with age, and age with time. Technological evolution, through the ages, has inadvertently continued to increase the size of human society's footprint on the planet more so than any other co-inhabiting species" (Jeyaretnam, 2005)

for example, some food for thought raised from Jeyaretnam and Berger we beg to ask the following questions;

- What is the human cost of development?,
- What social benefits does progress bring and
- Who profits from globalisation?

Also with the importance of technology in today's society and the ITC revolution, can we afford to pursue an untamed policy of natural capitalism; who will attend to the global issues rising from the third world threat of underdevelopment and environmental issues in these poor countries; and finally, what causes the debt crisis in poor countries? How will engineers deal with the spiralling global energy demands, as shown in Figure 4-1? The projections of world energy consumption up to the year 2025 indicated that one cannot observe any tendency to decrease disparities; in contrast, disparities are further increasing.

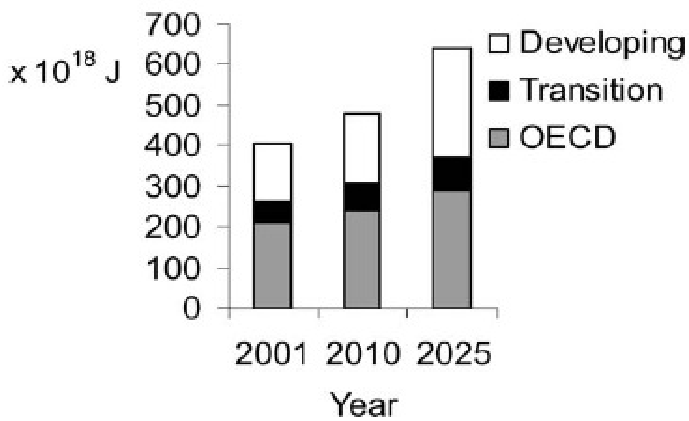

Figure 4-1: Global Energy Consumption 2001–2025 (Metzger and Eissen, 2004)

The aforementioned are the basis of this engineering enquiry. The discipline needs to be prepared to respond to the challenge in order to assist in devising solutions. There is a pressing need for engineering profession to resolve major conflicts of interests between egocentrism and the use, care and sharing of natural resources. However, the pressing issue is to quantify a collectively assess the sustainability issues in the engineering industry towards sustainability practices. Using a management adage often attributed to the quality guru Dr. W.E. Deming, "you can't manage what you don't measure". Hence, it is essential that engineers have some understanding of sustainability measurement tools so that they are able to design products and systems that will be sustainable and acceptable in the 21st century.

4.3 Natural resources and engineering

"There are many who, facing the next century, wonder if it will be possible and/or desirable to continue along the path of such prodigious change" (Miller et al., 1998) .

Industrialisation over the past century has brought profound technological, economic and social transformations affecting our natural resources of the earth's ecosystems. Natural resources such as minerals and crude oil are a finite supply, inherently unsustainable industries; however they are a vital commodity to global economies, livelihoods and the development prospect. Lave and Matthews(2001) defined natural capital as,

$$NC = NR + ES \qquad (4.1)$$

Where,

NR= Natural capital includes natural resources

ES = eycosystem services to provide habitat regulation of atmosphere, water and climate

4.3.1 Case study description -The Australian mining industry

Let us review a the importance of natural resource to Australian economy, the mining industry is Australia's second largest export earner (after manufacturing), accounting for 38% of the total value of exports in 2005–06, principally from the coal and metal ore mining industries (ABS, 2005).

		VALUE OF EXPORTS(a), By industry of origin			
					Share of total exports
Mining		Manufacturing	All industries	Mining	Manufacturing
$m		$m	$m	%	%
2001–02	32 507	69 111	121 108	26.8	57.1
2002–03	31 261	65 810	115 479	27.1	57.0
2003–04	28 565	62 442	109 049	26.2	57.3
2004–05	41 123	67 496	126 823	32.4	53.2
2005–06	57 107	74 958	151 792	37.6	49.4

Table 4-1 : Export figures on a free-on-board basis (ABS, 2005)

The composition of Australian industry has also changed dramatically over the last 100 years. Table 4-1 shows the proportion of exports contributed by the mining industry, based on exports by industry of origin. In the period 1995–96 to 2005–06, the value of exports from the mining industry has more than tripled. By comparison, the value of exports from the manufacturing industry has grown by 54%. As an end result, mining's input to total goods exported from Australia increased from 22% in 1995–96 to 38% in 2004–05, while ,manufacturing's share fell from 64% to 49% (ABS, 2007).

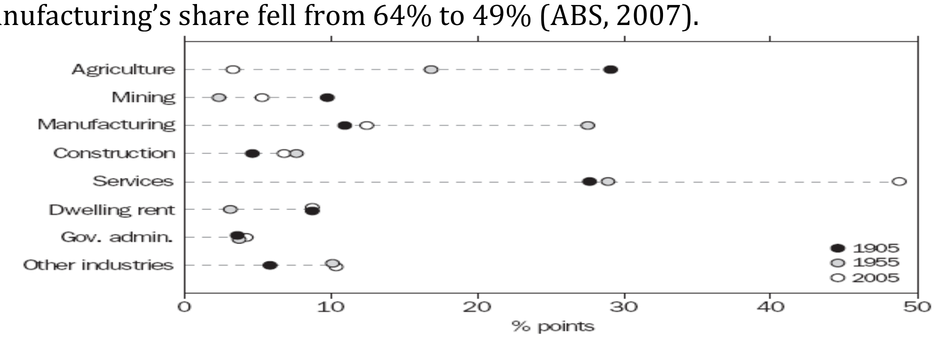

Figure 4-2: Industry shares of GDP (ABS, 2005)

Figure 4-2 shows data from 1904-05, 1954-55 and 2004-05. This graph highlights the contribution of the natural resource-based industry to GDP at all three time points.

	2002	2003	2004	2005	2006
	'000	'000	'000	'000	'000
Mining	1.1	1.1	2.0	2.7	3.9
Manufacturing	11.6	10.9	16.1	14.0	13.0
Electricity, gas and water supply	0.4	0.3	0.4	1.0	0.9
Construction	*9.2	*5.5	*7.1	*9.7	9.6
Wholesale trade	4.4	*4.1	7.3	*6.6	11.6
Communication services	0.4	0.5	0.7	0.6	*1.1
Property and business services	14.2	*18.8	27.7	31.9	35.3
Transport and storage	2.4	*1.6	*3.0	*4.5	3.1
Retail trade	10.9	18.1	21.8	21.1	21.6
Accommodation, cafes and restaurants	*6.3	5.0	*3.8	6.3	6.7
Finance and insurance	4.0	5.0	4.7	7.4	8.1
Government administration and defence	5.8	4.9	4.9	6.3	8.7
Education	3.1	5.0	4.5	4.1	3.6
Health and community services	11.1	12.0	12.1	14.0	14.9
Cultural and recreational services	1.9	3.6	*2.0	3.7	3.9
Personal and other services	*3.5	*3.1	*4.6	*4.0	*5.8
All industries	90.3	99.5	122.7	137.8	152.0
(a) Classified according to the Australian and New Zealand Standard Industrial Classification (ANZSIC), 1993 edition.					

Table 4-2: Job vacancies in Australia by industry (ABS, 2008)

Notably, an industry's share of Australian GDP should not be viewed as an indicator of an industry's performance but rather as a relative indication of how significant an industry is to the economy at a particular point in time (ABS, 2005). The highest number of job vacancies in any Australian industry sector in May in each of the past five years as indicated in Table 4-2 is the red colour-highlighted group in Table 4-2 which is directly affected by natural resources.

> "According to the law of one price, identical goods should (under certain conditions) sell for the same price in two different countries at the same time. It is the foundation for the purchasing power parity (PPP) theory, which relates exchange rates and price levels. The absolute PPP exchange rate equates the national price levels in two countries if expressed in a common currency at that rate, so that the purchasing power of one unit of a currency would be the same in the two countries" (Van Marrewijk et al., 2007).

In light of PPP theory let us review an example, of natural resource intensive and reliant economy like South Africa. According to Mohamed-Katerere (2006)the mining activity contributes an average of 10 per cent of the GDP and about 60 per cent of foreign exchange earnings of the countries of the Southern African Development Community (SADC). Similarly, Figure 4-3 lists GDP resource-rich countries (raw materials and processed products-natural resources and labour) versus purchase power parity. Australia, with an estimated $33,000 earning per capita, and with 38% of basic products, including raw materials and processed products based on natural resources and labour, falls in the unswerving position of the United States of America, as shown in Figure 4-3. Therefore management of natural resources by engineers is considered the frontline for the transitions towards a more sustainable and equitable development.

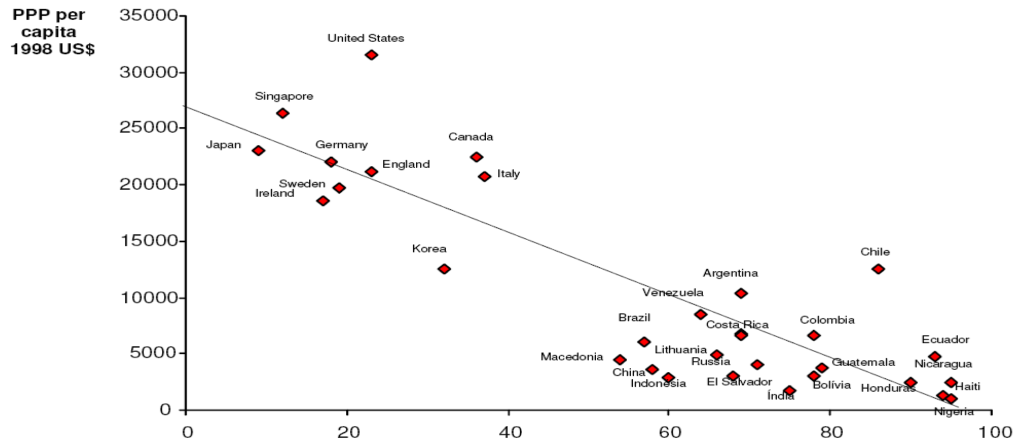

Figure 4-3: Percentage of exports basic products V purchasing power parity 1998 (IITC, 2002)

In the middle of the 20th century, coal was the main source of energy in the UK and atmospheric pollution in and around large conurbations, resulting in 'smog', which was a serious health hazard. Oil, which causes less pollution than coal, gained ground as an energy source until an energy crisis in the 1970s caused a rapid increase in its price. Natural gas, which causes less pollution than oil, has recently increased its share of the energy market. However, burning any of these fuels releases the greenhouse gas, carbon dioxide. All engineering actions ultimately have natural limits a cost on the planet and consequently environmental degradation is a primary indicator of unsustainable social and economic systems. Thus the pro growth argument reported by Dorf (2001) to expect technology to overcome natural limits is arguably a false one. It claims market prices will rise and will thus drive technological change for substitutes for resources. For example, petroleum reserves are depleted; the market price of oil will rise and provide a drive for replacement sources such as renewable energy. However renewable energy remains governed by the same physical limitations not to mention entropy and the laws of thermodynamics. There appears to be a little acceptance of natural limits in Engineering and what the limits are and how to ensure that these limits are not exceeded. Nonetheless, solid agreement on mutually reinforcing goals is apparent on economic growth environmental preservation and protection, and social equity. A simple summary of these triple goals is to quote (Dorf, 2001) where Qol is the quality of life,

$$Qol = EG + EP + SE \tag{4.2}$$

Where,

EG =Economic growth
EP =Environmental preservation and protection
SE= Social equity

However, it would be difficult to accept the addition of equation 4.2 unless all three parameters can be expressed in the same units; hence quality of life (Qol) is better expressed as

$$Qol = f\left(EG + EP + SE\right) \tag{4.3}$$

4.3.2 Case study description -The Australian chemical industry

The Australian chemical industry is fundamental to the Australian economy; the impact on GDP is shown in Figure 4-4. Kolm (2000) writes the chemical industry is one of the few technology-based and fully-integrated industries in Australia. It is highly technical by nature, due to this character; it had to be part and parcel of international technology. Inevitably a great extent of the technology had to be imported, either through a licensee or by creating a local subsidiary of international companies. However local engineering R&D played a significant role, to be competitive and to adapt technology successfully, local research, development. Indeed, for many decades, the industry has been a leader in local industrial research. Although "it represents roughly only one tenth of the Australian manufacturing industry, it has carried out about one quarter of its private sector research". But to its demise the public perception of the chemical industry "is that it is the worst polluter. In fact the word ''chemical'' conjures up a fearful image"(Sikdar, 2007b). The Chemicals and Plastics industry is a diverse manufacturing sector comprising of widely differing areas; base and feedstock products, speciality and refined chemicals, intermediate goods and components as well as finished products.

> "It plays an important role in manufacturing, with 70% of its outputs used as essential inputs to other manufacturing and industrial sectors (automotive, building and construction, packaging, medical, agriculture and mineral processing)"(Productivity Commission, 2008).

By 1985, its turnover (including plastics, paint and pharmaceuticals) was 10,840 million dollars, its added value 3,923 million dollars and it employed 83,630 people (Industries Assistance Commission Report, 1986). It is also one of the country's key strategic and enabling industries, on which other industries depend (Australian Academy of Technological Sciences and Engineering, 1988). In 1986, investment was estimated to have exceeded 2500 million, employing 10,000 people and assisting the export revenue. The industry accounts for 21 percent of research conducted in the manufacturing sector (ACIC, 1986).

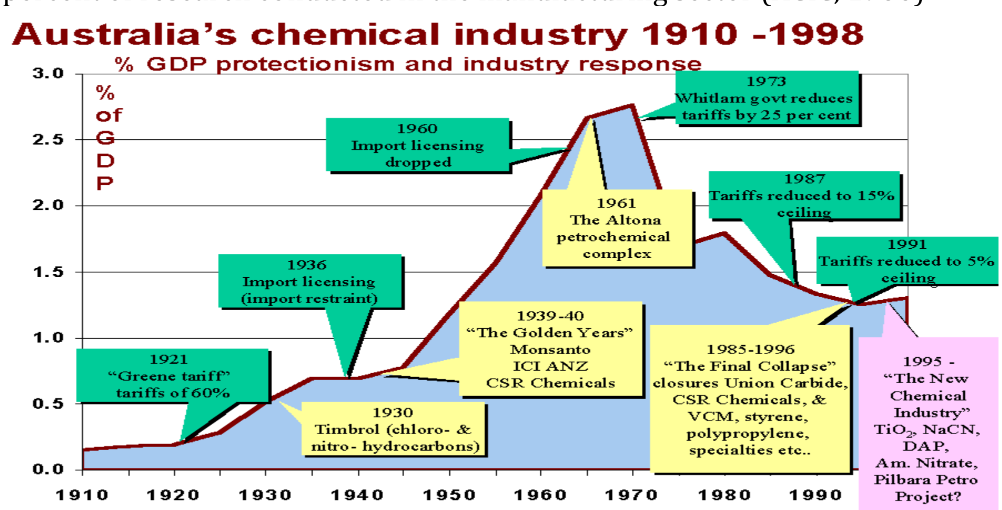

Figure 4-4: Australia's chemical industry 1905 -1995. Value added as % GDP, (Van Santen, 1998a)

Peaking in the mid 1970s, after twenty five years of strong growth to represent an almost 3 per cent of GDP, the downfall of the chemical industry in terms of GPD to collapsed to just one-half its peak GDP in only two decades (Van Santen, 1998b). With the reduction in tariffs and the undoing of protectionism in the late 1980s came a decline. In 2004/05, the annual turnover was over $30 billion or 9% of total manufacturing. The industry employed over 82,000 people or about 8% of the total manufacturing industry workforce. It added about $9 billion in value or about 9% of total value added by manufacturing. However, annual imports of about $14 billion make up 9% of the total manufacturing sector's import bill. Furthermore, imports have grown at an average annual rate of 3.4% in the three years to 2004/05. Thus, even with annual exports of around $4 billion, there is a significant balance of trade deficit (Australian Government, 2004).

Traditionally standard financial indicators have been used track companies business effectiveness (Krajnc and Glavic, 2003). Nowadays, due to demands from the wider community , sustainability reports are emerging as a new trend in corporate reporting, integrating into one report the elements of financial, environmental, and social facets of the company (Global Reporting Initiative, 2002). Sustainability reports usually introduce a set of indicators that can be used to measure the sustainability performance of a company. usually These reports translate sustainability issues into quantifiable measures of economic, environmental, and social performance (Azapagic, 2004) and to provide information on how the company contributes to sustainable development (Azapagic and Perdan, 2000). Sikdar(2003a)reported on indicators for use in chemical process, a manufacturing site, or a manufacturing enterprise Important sustainability reporting progress has developed since the foundation of the World Business Council for Sustainable Development (UNEP, 1997), with incremental achievements at the foundation of the (Global Reporting Initiative, 2002) to finally the development of standards for environmental management systems, such as the ISO 14000 and EMAS standards (OECD, 2001). One of the significant studies on sustainability metrics was sponsored by the Centre for Waste Reduction Technologies (CWRT) of (AIChE, 2004) for evaluating process alternatives. The other significant effort was made under the auspices of the (IChemE., 2002) in the U.K. In this effort, the indicators are specifically grouped into environmental, economic and social categories. (Veleva and Ellenbecker, 2001) reported on the dimensions and qualities for indicators of sustainable production, including their.

4.4 Environment and engineering considerations

This section aims to raise awareness of the important role of natural capital including environmental considerations to engineering technology. It is worthwhile to comment on Beder below quote, where engineers and engineering need to incorporate environmental consideration as core key criteria.

> "Natural resources, or living systems, considerations have been peripheral and secondary at best, something forced upon the engineer as a community. Environmental considerations are marginalised in the design process to the extent that Environmental Impact Statements deal with gross impact of design. This treatment

of environmental impact, if applied to economic impacts, would be akin to designing each part of a project without concern"(Beder, 1993a).

The quality of life enjoyed by many of the developed nations in the 21st century is attributed to advances in engineering and technology; these advances come with their own environmental limitations. The following are two scales of some dramatic examples of failed design considerations;

Macro

- Climate change
- Ozone depletion
- Increased levels of carbon dioxide
- Acid rain

Micro

- The legacy of the Chernobyl nuclear accident;
- The disastrous aftermath of accidental chemical releases at Bhopal;

"In many instances, failure of a technology occurs as a consequence of events that have not been identified and planned for in advance" (Hay and Noonan, 2002).

Whilst climate change is currently a controversial issue it is argued by its proponents in the scientific community as being the result of human activity mainly from the industrialization in the developed nations. Similarly it can said that engineers did not fully anticipated or appreciated the possible effects upon the environment, and human health, safety and welfare (Mckibben, 1990). Consequently 20% of the world's population live in the developed nations and consume 80% of the current natural capital flow. Dorf (2001) proposed two strategies to reduce environmental impact of technology

- Substitute of intellectual capital (IC) to reduce the demand on natural capital (NC).
- Cut-back in material and energy inputs to economic processes is one sure way of cutting back on waste and pollutants.

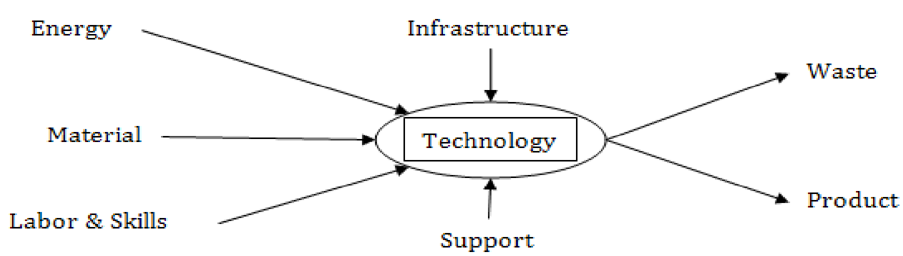

Figure 4-5: Components of a technological system source (Hay and Noonan, 2002)

As per Hay and Noonan (2002) definition of technology it consists of seven equally important dimensions as shown Figure 4-5. Zeleny (1986) defined technology to consists of three interdependent, codetermining, and quality equally important components.

"Hardware: the physical structure and logical layout of the equipment or machinery that is to be used to carry out the required tasks. Software: the knowledge of how to use the hardware in order to carry out the required tasks. Brainware: the reasons for using the technology in a particular way (know-why)."

In addition to the above three components, Khalil (2000) considers a fourth know-how. In the 1930s, the German economist, Schumpeter, noted that technological innovations are not evenly distributed over time or across industry, but appear in periodic clusters. These techno-economic revolutions depend on clusters of mutually-supportive technological innovations being accompanied by social innovations (Dodgson, 2000). The waves shown in Figure 4-6 illustrate the progression of technology along with time. Considering the development patterns of technology let us consider a contemporary issue of energy, climate change and efficiency in the next section. In order to review the issue of energy efficiency in engineering from a global perspective we would like to refer to Pacey (1983)

> "examples of big dams feeding leaking pipes and electricity generating stations pumping heat into the atmosphere when electricity is mainly used for heating" (Beder, 1993b).

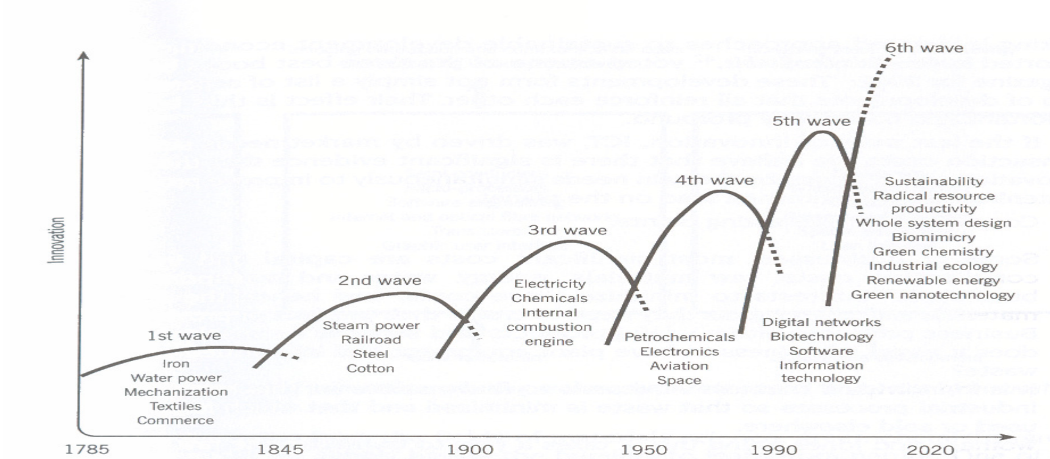

Figure 4-6: Waves of innovation (Hargroves and Smith, 2005)

4.5 Climate change and green house gases

Climate change and green house gases are a global environmental problem that directly effects the engineering profession. It requires a greater engineering consensus to reduce carbon emissions and consequently, the planet's energy footprint. According to Estrada-Oyuela (2002) the rate of greenhouse gas mitigation in relations to quality of life is identified by the following

$$G = \left(\frac{Q}{P}\right) \times \left(\frac{Y}{Q}\right) \times \left(\frac{G}{Y}\right) \times P \qquad (4.4)$$

Where,

Q/P= Quality of life per capita
Y/Q=Material consumption required per unit of quality of life
G/Y= Greenhouse gas (GHG) emissions per unit of consumption
P = population

So one method of resolving the aforementioned issues in addition to improving the quality of life and reduce GHG is to develop green energy. For this reason, research into alternative energy is a growth industry. Figure 61 reviews the renewable energy alternatives available. Generally renewable or alternative energy relies on a variety of power generation sources which are derived from renewable resources such as wind and solar energy. The major deterrent to renewable or alternative energy remains the financial drawbacks, that is, the cost per kilowatt-hour for renewable energy.

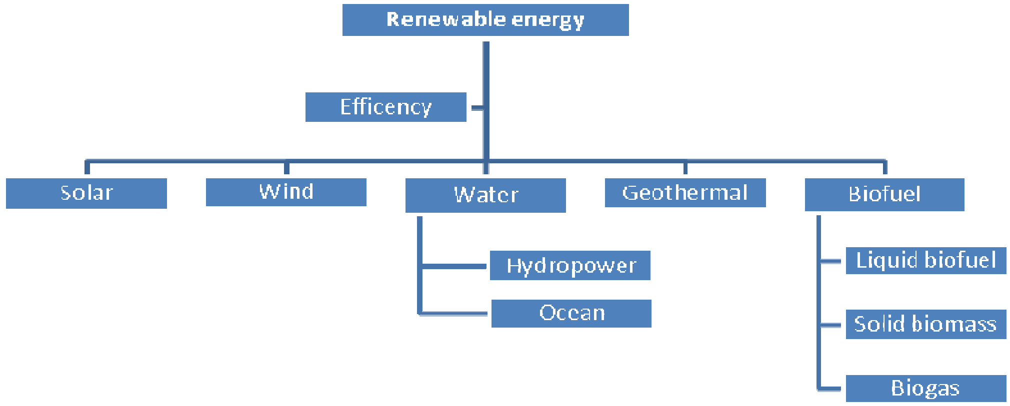

Figure: 4-7 Renewable energy alternatives (Hasna, 2009d)

Coal is the most abundant fossil fuel in the United States, providing over 50% of domestically-produced electricity, and amounts to a $200 billion industry. A key component to keeping coal attractively priced is continued technological advancement. The costs of generating electricity deemed dependable supply according to (George, 1960; Pouris, 1987; Lee and Verma, 2000; The Royal Academy of Engineering, 2004; Johansson and Goldemberg, 2004-05) are summarized in Table 4-3, which illustrates the present day costs of generating electricity from different types of technology. The cost of generating electricity, in terms of a unit cost (cents per kWh), delivered at the boundary of the power station site for coal is 4 ¢/kwh. Whilst it is not the cleanest, it is certainly the cheapest and is deemed as dependable or a firm supply. In this instance, low efficiency has $C0_2$ consequences.

4.5.1 Case study description-energy efficiency

The individual unit of study described in this section is made up of a series of three case studies emphasizing a similar theme of "energy efficiency issues and relationships with sustainability to avoid being divorced from global context. This requires tackling the idea of development of technology and natural resources in engineering. The first section introduces the case studies with a brief process description, followed by a sustainability analysis and discussion.

Case study 1: Coal-fired electric power plant

The basic components of a simplified fossil fuel coal power plant are shown schematically in Figure 4-8. To facilitate efficiency analysis, the overall plant is broken down into three subsystems identified A to C in a simple flow chart.

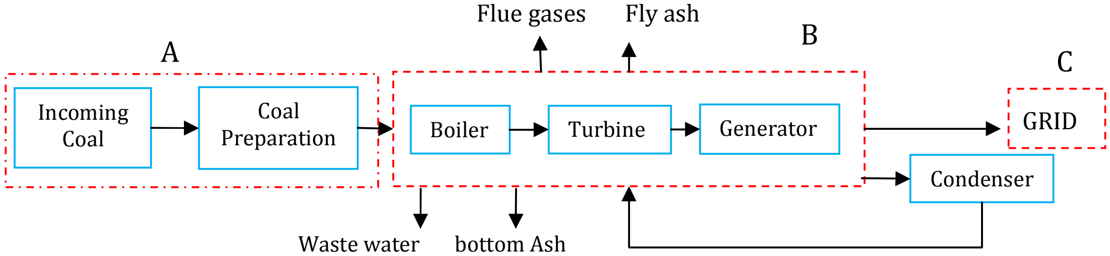

Figure 4-8 Chain of electricity generation from coal to electricity (Hasna, 2009d)

The focus of this case study is in section B: power generation, where energy conversion from heat to work occurs in a typical thermal coal-fired electric power plant. Components of a thermal power plant are the incoming coal-handling system, water treatment plant, boiler feed water arrangement, flame control system, re-heater, super-heater, economizer, steam turbines, and turbo-generators with auxiliaries.

Case study 2: Industrial pump systems

Motors are an important machine in a chemical or manufacturing plant, it produces useful work by causing rotation. This example refers to a pump system where, the electric motor draws either single or three phase power from the mains to drive the pump. The drivetrain, or transmission, connects the motor shaft to the pump where the transmission transfers virtually almost 100% of the power from the motor to the pump. Therefore, the pump assembly with a throttle moves the fluid to the required level.

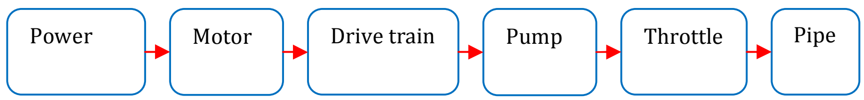

Figure 4-9 Industrial pumping system (Hasna, 2009d)

Case study 3: Microwave oven

The microwave oven consists of the line or supply voltage as shown in Figure 4-18. The alternating current (AC) is stepped up to thousands of volts (high voltage), the high AC voltage is stepped up to an even higher DC voltage, and then converts the DC power to generate microwave energy. The microwave energy is generated using the nucleus of the high-voltage system, the magnetron tube, which is a diode-type electron tube that is used to produce the required 2450 MHz of microwave energy.

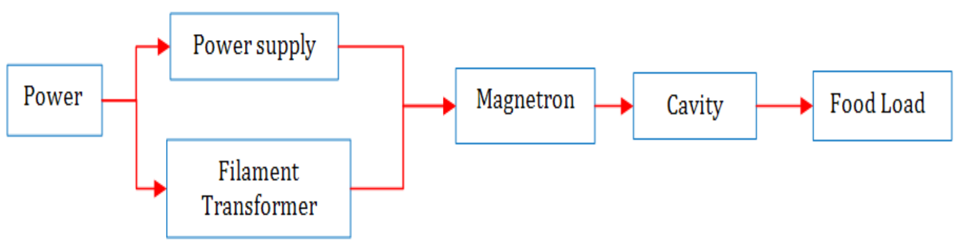

Figure 4-10 Typical microwave oven (Hasna, 2009d)

4.5.2 Case study analysis-energy efficiency

To better understand the promise of technology efficiency in sustainability, it is helpful to first know how it fits in the global scheme of things. The following section examines three case studies: coal power plants, a pump system and a microwave oven individually to establish their fitness for energy efficiency upstream and downstream (Hasna 2009d).

Analysis: Coal-fired electric power plant

The typical operation of a coal power station would begin by the coal initially being shipped to the power plant by rail car. At first, coal may contain trace amounts of chemicals which are usually accounted for under the EPA's Toxics Release Inventory program. The objectives of the coal preparation plant are to remove impurities and produce consistent fuel products within specified ash, sulphur and moisture contents. Recognizing the importance of the Rankin and Carnot cycles (pressure-volume and temperature-entropy studies) in thermal steam plants, this analysis is limited to ascertain an approximation for conversion efficiency under normal operating conditions. The boiler produces steam (thermal power) which is then transformed using a turbine into rotational energy; however, not all thermal energy can be transformed into mechanical power. This means that some of the energy of the coal that is used to heat the steam is lost. The typical boiler losses are most significant in terms of heat loss in evaporation, heat loss as the specific heat of water from combustion, and heat loss due to combustibles (unburnt carbon) in the fly ash. In addition, the turbine efficiency is directly affected by the boiler where any changes in the heat distribution in the boiler due to changes in gas flows, or the effects of ash emissivity and slagging on heat absorption may result in reduced turbine efficiency because of reduced steam temperature. Naturally, there are other inefficiencies linked to the operation such as coal handling equipment, pulverizing mills, fans, ash handling equipment, and the flue gas cleaning plant. Therefore, if we consider the simple material balance shown in Figure 4-11, where 48 percent of the energy is waste heat, the figures are beyond belief.

Figure 4-11 Energy flow for the world's thermal power-stations (Ramage, 1997)

Coal properties have a large impact on both the thermal efficiency of the power plants and the specific CO_2 emissions from the plants. According to the second law of thermodynamics, the thermal conversion efficiency is reported on between 30% and 40% (PERSPECTIVES, 2006; Ramage, 1997) however the efficiency of the Australian coal power stations is improving over time. According to Akmal and Riwoe (2005) Kobayashi (2008), the national average thermal efficiencies was 33.3% and Okura et al. (2003) reported on a state-of-the-art plant in Japan that reached a maximum of 44.2%, whereas the European commission had published similar data with some improved efficiencies nearing 2004, as displayed in Figure 4-16. This energy efficiency improvement was due to a combination of factors including the closure of old inefficient plants, improvements in existing technologies, installation of new, more efficient technologies, often combined with a switch to fuels with a better generating efficiency, such as from coal power plants to high-efficiency combined cycle gas-turbines. In analysing the coal power plant, it is appropriate to point out that historically, coal fired plants have always had the biggest market share. The vast majority of electricity production is generated in coal fired plants (Soares, 2007), as illustrated in Figure 4-13.

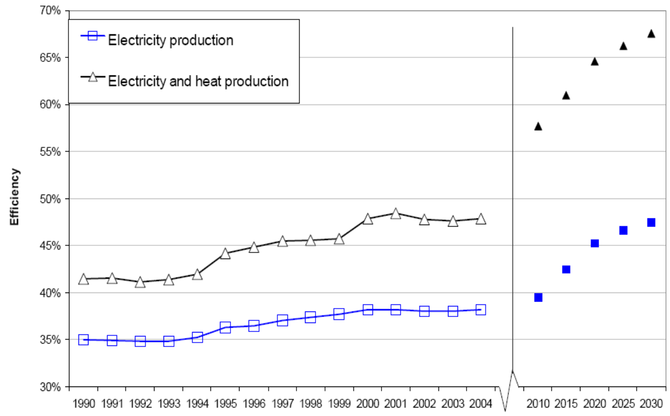

Figure 4-12 Efficiency of conventional thermal electricity (Commission, 2006)

As a result, we have seen that the majority of electricity generation is produced using fossil fuels, coal in particular, with associated environmental impacts such as greenhouse gas emissions and wastes. In order to understand conversion efficiencies, some properties of the energy supply chain need to be elucidated.

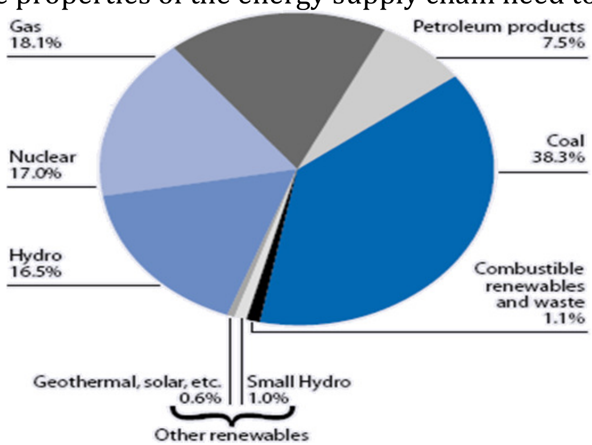

Figure 4-13 World electricity production by source (IEA, 2003)

Technology interaction with the environment and the end-user are schematically represented in Figure 4-15, whereas the demands of the end user are translated into functional criteria that must be fulfilled by the technology for the coal power plant. For this reason, technology is included as part of the four dimensions of sustainability. Hence, to create greater energy efficiency and cleaner energy, technology remains the centrepiece of systems design needed for a rapidly developing world. Referring to the energy supply chain from natural resources listed in Figure 4-14, the link between natural resources, end user and technology is that it provides satisfaction of human needs. This satisfaction has benefits and inherent conversion efficiency. Improving conversion efficiency to seamlessly achieve sustainability in one sense is a contradiction. The concept of technological rationality improves conversion efficiency by developing more advanced technology. This begs the question: was sporadic development and consumption not a problem to begin with? This oxymoron states that the very means of improving conversion efficiency is by consuming more, which is self-contradictory. Therefore, the engineer's legacy is to achieve the satisfaction of human needs and maintain quality of life through the aid of technology.

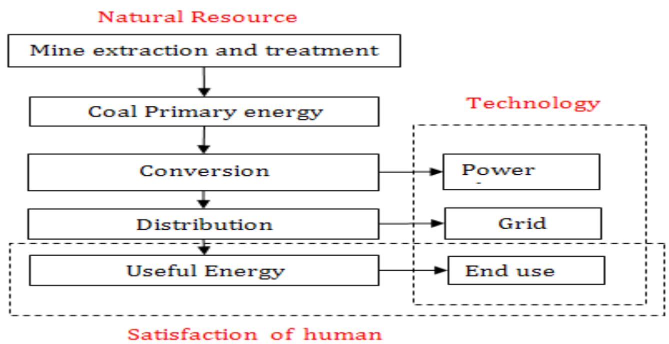

Figure 4-14 thermal power Conversion chain (Hasna, 2009d)

A few researchers have tackled the idea of design intention with several lingering challenges, particularly in conversion efficiency that must be overcome before any sustainability potential can be realized.

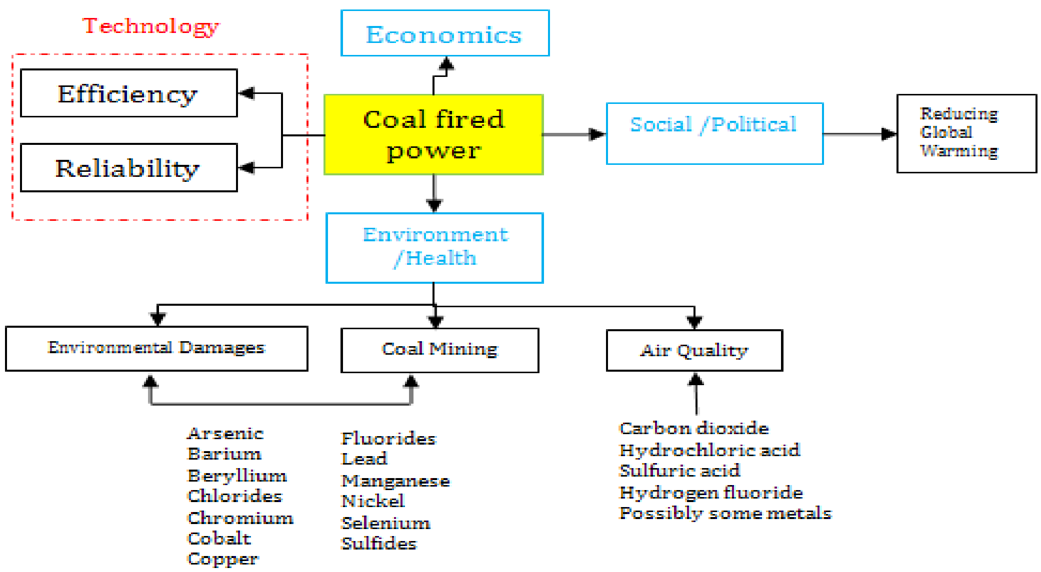

Figure 4-15 Analysis of coal fired power station (Hasna, 2009d)

As shown in Figure 4-16, the energy conversion of the coal plant, efficiency, directly leads to GHG and ultimately climate change. According to Sondreal et al. (2001), coal is at a crossroad, it either needs to resolve its environmental challenges and regaining its competitive edge, or suffer a possibly precipitous decline with ratification of the Kyoto Protocol.

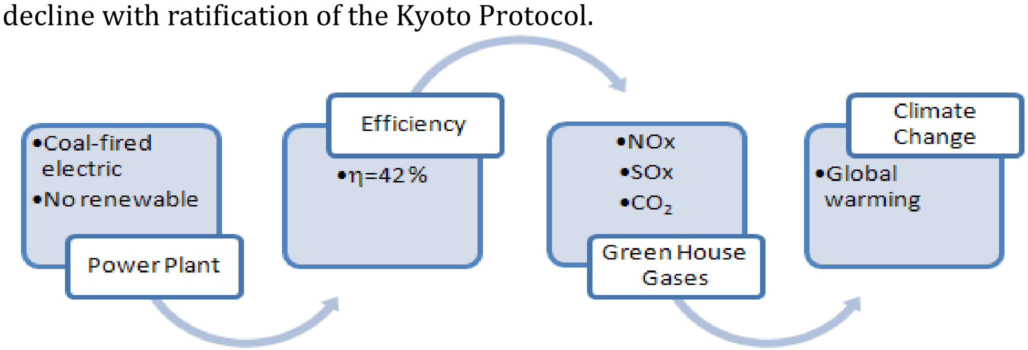

Figure 4-16 Energy conversion chains (Hasna, 2009d)

Technology	Current energy cost	
	All costs are in US$-cent per kilowatt-hour	
	¢/kWh	$/GJ
Biomass energy		
Electricity	3–12	
Heat	1–6	
Ethanol		8–25
Bio-diesel		15-25
Wind electricity	4–8	
Solar		
photovoltaic electricity	25–160	
thermal electricity	12–34	
Low-temperature solar heat	2–25	
Hydro energy		
Large	2–10	
Small	2–12	
Geothermal energy		
Electricity	2–10	
Heat	0.5–5	
Marine energy		
Tidal	8–15	
Wave	10–30	
Tidal stream/Current	10–25	
OTEC	15–40	
Coal plant		
Pulverised fuel (PF) steam plant	3-4	
Circulating fluidized-bed combustion (CFBC)	3-4	

Table 4-3: Cost of Generating Electricity(Hasna, 2009d)

Analysis: Industrial pump systems

Pumps are used to deliver liquids through piping systems. On a typical industrial site, pumping is the largest application of motors, and motors use three-quarters of all industrial electricity (DETR Department of the Environment Transport regions, 1998; Lovins et al., 1999). Therefore, pumping is a key area to target for energy efficiency. Figure 4-17 illustrates a flowchart of a typical pump chain of energy conversions (i.e. the conversion efficiency of primary into secondary energy) and the energy loss data adapted (Lovins, 2005; Norton, 2004).

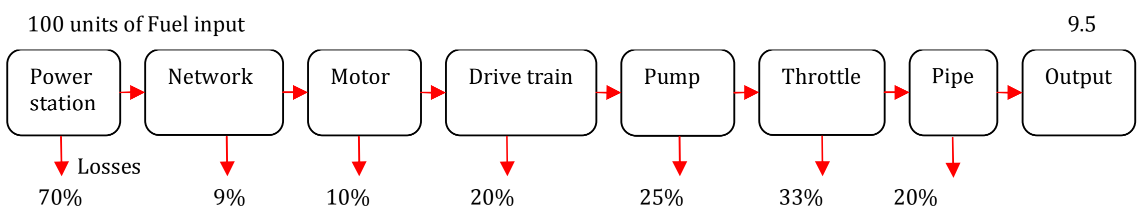

Figure 4-17 Industrial pump system (Hasna, 2009d)

In energy conversion efficiency for a pumping system, listed in Figure 4-17, which starts upstream at the power station where the primary energy, 100 units of fuel, progresses at various stages to reach the motor and is then piped downstream, we see the conversion chain losses. The effectiveness of the conversion process is characterized by primary into secondary energy, plus the delivery efficiency from secondary to end user. A number of known losses contribute to the distribution efficiency of delivering secondary energy from the point of conversion to the point of end-use. For example:

(a) The motor converts electricity input into torque and the remainder is lost due to heat and vibration. The effectiveness of the pump conversion process is characterized by the motor efficiency which is a ratio of mechanical output to electrical energy input;

$$\eta_{motor} = \frac{mechanical\ power\ output}{electrical\ energy\ input} \quad (4.5)$$

> "The degree of perfection of the conversion process between the mechanical work supplied and the mechanical energy of the fluid is expressed by the pump efficiency" (Cengel and Turner, 2005).

(b) The inevitable energy losses due to mechanical friction and the turbulence created in the fluid as it passes through it (Mott, 2006) results in more power being needed to drive the pump than the amount that eventually gets delivered to the fluid (Cengel and Boles, 2006).

$$\eta_{pump} = \frac{mechanical\ energy\ increase\ of\ the\ fluid}{mechanical\ energy\ input} \quad (4.6)$$

Energy savings are possible through properly matching pump specifications to the system requirements. These potential savings are compared to those attainable through the use of high efficiency motors and improved pump efficiency.

(c) Over-design it is common practice to add approximately 10% to the estimated frictional losses of a pipe work system design, then to specify pumps based on the elevated figure, resulting in oversized pumps. This practice allows for any fall-off in pump efficiency through wear, and to allow for any pipe work fouling which may occur as the system ages (DETR Department of the Environment Transport regions, 1998). Finally, the energy cost is the highest component of the total life cycle cost of the industrial pump. Therefore, minimizing energy by increasing efficiency is a major goal towards sustainability.

Analysis: Microwave oven

According to the American Council for an Energy-Efficient Economy cited in and (Cengel and Boles, 2006), cooking in a microwave oven reduces energy use by about two-thirds of the energy used for conventional cooking. However, if we review the energy consumption stages of a typical microwave oven, the power drawn from the wall is deduced using equation (4), where I is current and V is line voltage.

$$P = IV \quad (4.7)$$

Using the data listed in Figure 4-18, P= 1595 where V=120 V and I=13.3 amperes (A), this power is known as the oven power; however, the output power using load test is about 700W; hence, the efficiency of power transfer would be 700/1595 =0.44 or 44%. The conversion efficiency at various stages of the process, as shown in Figure 4-18, clearly shows the efficiency of magnetron which is a major component of the appliance and comprises a large percentage of power losses at 35% of energy in yielding it, therefore a not-so efficient process. Nowadays, microwave ovens have increased the overall microwave oven efficiency; however, it is still around 44 per cent according to Buffler (1992) and 54 percent according to Tetsuji (2005).

Finally, if the efficiency of the power plant supplying the energy and its distribution network and the microwave oven are added together, the end user energy conversion efficiency would reach a figure above 70% in losses. Hence, the efficiency of a cooking appliance represents a fraction of the energy supplied to the appliance that is transferred to the food and this resembles our energy consumption legacy.

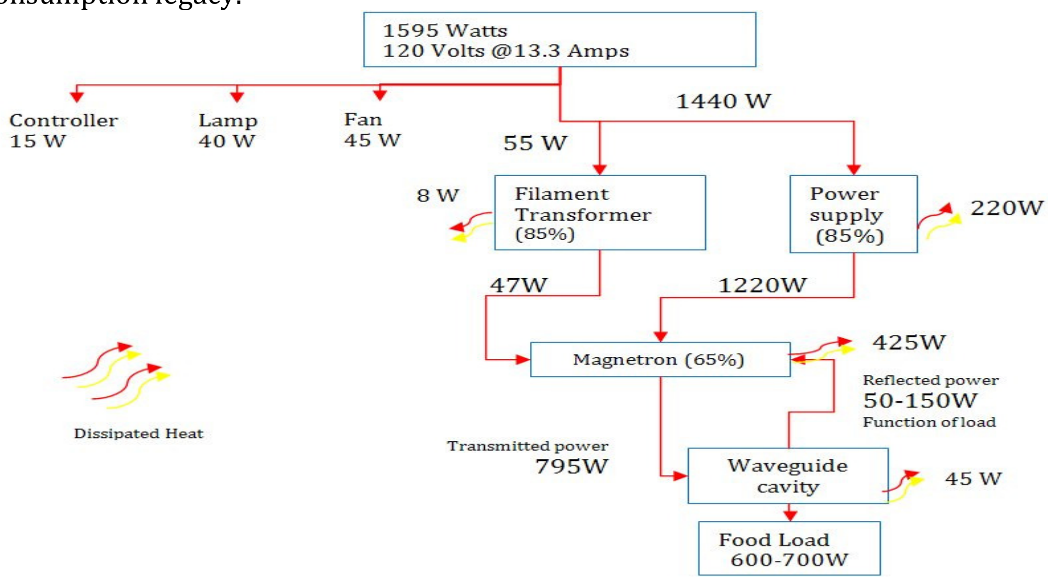

Figure 4-18 Efficiency of the microwave oven (Hasna, 2009d)

4.6 Engineers, society and liability

> "Engineers are often assumed to be instrumentalists, meaning they believe that technologies and technological artefacts are intrinsically value-free, only acquiring moral significance at the point at which they are employed by human agents for particular uses" (Newberry, 2007).

Engineers respond to problems in society adhering to a professional code of practice which integrates social and anthropological contents (ethical, moral, human). Additionally, a preoccupation to conserve nature, respect, solidarity and international cooperation is manifested in the work of engineers. A philosophy of engineering forms an ideological structure that aids engineers know where they stand in relation to issues of economic and moral importance. Engineering philosophy includes elements of many other different philosophies, a mosaic of philosophy types.

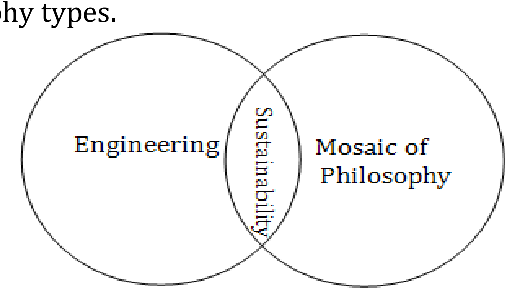

Figure 4-19: Merger of entities with hypothesis of by-product (Hasna, 2007a)

Figure 4-19 shows an abstract view of living life with mutually inclusive types of philosophy. Therefore, in order for the engineering profession to facilitate a healthy relationship with technology and the wider community, we must break out of the cycle and focus on a balance of many of these philosophies that would make for good engineering management, but mostly that would simply make us better human beings, since the purpose of technology is to provide a better standard of living.

An early and important division of philosophies was developed between Empiricism, which professed the importance of practice and knowledge gained through experimental observation, and Rationalism, which said that theory was the most important aspect of knowledge (Lacey, 1986). Post-modernism's focus is on human understanding as only interpretation. This calls into question how we interpret the world around us (Johnston et al., 1999). It is impractical for an engineer to call into question his interpretation of a project situation on such philosophical grounds alone. Science is a major discourse in engineering. Therefore, a philosophy of science may hold many keys to what may best describe a philosophy of engineering. Elements of a philosophy of science may feature in a philosophy of engineering. However, an important difference between the scientist and the engineer is the application of scientific knowledge necessary in engineering. Therefore, there is a practical element to engineering which is not necessarily present in science, as shown in Figure 4-20.

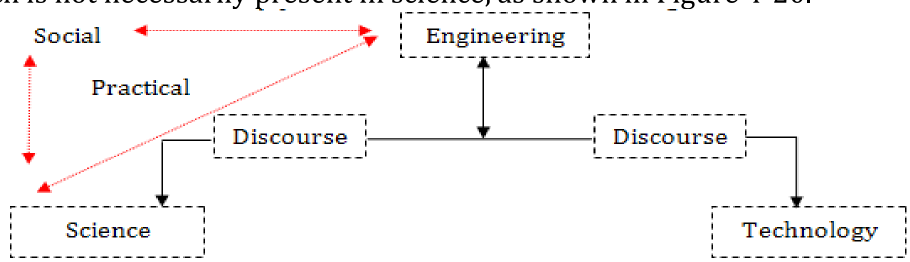

Figure 4-20: Engineering discourse of science (Hasna, 2007a)

Engineering is known for its ability to produce solid results, in combination with the commonalities of science and technology, as both are based on the gathering of knowledge. However, the most important aspects of this philosophy for an engineer lie in a discussion of what is called 'discourse'. This is, as (Foucault, 1970) explains, "a set of possible statements which produce the meaning and values of a cultural formation" (Johnston et al., 1999). This is useful in describing the 'discourses' which act to make up engineering, as Figure 4-20 illustrates the flow pattern of this relationship. That is, as engineering is partially socially constructed, engineers and members of society are bound to act within the cultural form, which is made up of meanings and values.

4.6.1 Engineering ethics and sustainability

Principles, morals and values are positioned within the context of human conviction; the industrial revolution affected our life styles and our interaction with the environment, economic developments. Managing sustainability involves incorporating the needs of users of the information; it requires participation, community involvement, transparency of decisions, and consideration of all affected stakeholders (Meadows, 1998; Rhydin, 1999; Clarke, 2002). Such decisions will be more effective due to the broad ownership of affected stakeholders. Obtaining consensus at different stages of the process is challenging (Dovers, 2001). However, the fact remains that building support for an initiative is critical if it is to succeed in changing attitudes toward sustainability and will likely avoid expensive litigation (Potts, 2003). However, questions regarding environmental depletion, particularly in the third world, remain unrequited. What should the engineer's position be, if offered lucrative work to deforest the Indonesian rainforest, or to split open the Himalayan Mountains, or mine Kakadu National Park? The engineering discipline has not yet founded the framework to understand the links between engineering and ethics, or to fully understand how innovation and sustainable engineering practices may influence each other.

> **"**Sustainability is a term used globally to describe an approach to life; it is also a chance to reassert the value of social and environmental stability. The ethical dimension of sustainability is basically about balance: balancing care for the earth with care for fellow humans" (Hasna and Thorpe, 2005).

4.6.2 Engineers and risk

According to Giddens (1999) the term 'risk' materialized into the English language from the Portuguese coined to describe voyages. Risks are inherent with innovation (Lloyd, 2005); engineering is synonymous with innovation including the risk of failing to achieve adequate monetary returns to cover the investment in developing innovation. Today the idea of risk in society risk aversion is the dominant philosophy, with dangerous consequences as it is believed that society can control the future which is a major break in the history of civilisation. Hence one way to view sustainability consideration in engineering projects is a way to minimize risk. This can be achieved using the National Academy of Sciences (1983) risk assessment framework. Of course, cost will play a key role in the way sustainability risk is accepted. Today the international community has sets limits on how much they will spend on risk-reduction for climate change. As for engineering a starting point can be that we harmoniously incorporate sustainability into engineering design in the same integral way we consider economic value. Foster (1980) discussed at least four ways used to establish the level of acceptable risk. These are:

(1) Risk aversion or absolute safety;
(2) Risk balancing or comparative risk;
(3) Cost/effectiveness; and
(4) Cost/benefit balancing.

4.6.3 Sustainability legal requirements

Sustainability law would represent an attempt to develop a system of laws and policies that facilitate processes, products, and patterns of behaviour which are good for the planet (Hasna, 2009f). Environmental law is plagued by a failure to apply contemporary scientific knowledge and understanding, reflected in a reductionist approach that underestimates the complexity, uncertainty, and unpredictability of biological and physical systems (Ludwig et al., 1993). In contrast, sustainability law would be firmly rooted in science and the laws of nature, beginning with a clear understanding of the laws of thermodynamics and explicit recognition of the biophysical limits of the planet Earth. Scientists have observed that "thermodynamic laws are ideologically neutral but when combined with the concept of sustainability, have far-reaching consequences" (Holmberg et al., 1996).

4.6.4 Vicarious liability

Australian State and Federal anti-discrimination legislation states that an employer may be legally responsible for discrimination and harassment which occurs in the workplace or in connection with a person's employment unless it can be shown 'reasonable steps' have been taken to reduce this liability. Vicarious liability simply means indirect responsibility for the acts and behaviour of another (Ashley, 2004). This legal responsibility is called 'vicarious liability' and is incurred when the employer does not exercise reasonable care to prevent and promptly correct any harassing behaviour.

Under Australian law the employer is almost always liable for the actions of the employee under the principle of "vicarious liability" and usually has an insurance policy as a safeguard (APESMA, 2004). Similarly with professional negligence, where there has been a growing concern clarified by the institute code of ethics. More recently, professional liability insurance has become part of engineering practice. Vicarious liability, traditionally, was liability from the relationship between defendant and the infringer.

Guilty by association is an expansion of liability by relationship (Trench Failure, 2002). Therefore the concept of a non-delegable duty is used to justify the imposition of liability on one person for the negligence of another to whom the former has entrusted (or 'delegated') the performance of some task on their behalf (Parliament House, 2002). When analysing the fundamentals it remains that "personal guilt" is as a fundamental to concept of criminal jurisprudence. As for engineers vicarious liability, at least for accomplices, is as old as the common law Dressler (1985). At common law, certain accomplices were traditionally punished for the crimes of the perpetrator, such as a defendant who through fraud, coercion, or manipulation consummates the crime through another person (Noferi, 2006).

Let us review the of 'Viasystems (Tyneside) Ltd versus Thermal Transfer (Northern) Ltd' reported by (Transfer, 2005) where the companies were trailed for dual vicarious liability its potential significance for the engineering profession is significant, it was published in the news section of Engineering Management in Dec/Jan 2005/06. The case could have presaged major changes to commercial relationships between contractor and sub-contractor. The essence of the case was about a sub-contractor's labourer that caused flood damage to a factory by his carelessness. He had been following instructions given to him by the contractor, yet these resulted in a multi-million pound claim. The Court of Appeals (below the House of Lords) decided that both parties were responsible a split was deemed to be 50/50. Luckily, both parties were insured. This represents a change. Historically, it has always been the legal position, certainly since the 19th century, that dual liability was deemed impossible: in law, a dog could have only one master. However in this case the blame was apportioned between two parties. This is a change in the rules of engagement since traditionally it's been the tort law which pursues the deepest pocket (Clapham, 2006).

> "As a result of a number of key decisions in recent years, there has been a dramatic expansion of the ambit and scope of an employer's no-fault liability for torts committed by employees. More specifically, these decisions have set out a new and broader approach to determining when an employee's tort has been committed during the 'course of employment" (McIvor, 2006)

In a similar but different example of vicarious liability, Dzida and Kane (2006; 2006) explained the liability of a diocese for the actions of its priests. Where victims of clerical sexual abuse could sue the diocese in which the offence was committed just because the diocese has more assets than the priest abuser, and ultimate responsibility for the actions of a priest lies with his bishop. What we can learn from these examples in the midst ethical awakening, environmental awareness and sustainable practices in engineering is to largely promote sustainability and comply with governing legislation.

4.6.5 Globalisation and internationalisation

Globality, globalisation, globalism - these are all new words in engineering that have come into usage since the 1960s,. Despite the relative newness of these words, it abounds in the literature on global environmental change (Voisey and O'Riordan, 2001). Globalisation is a captivating term used far and wide, sometimes without clarity of meaning. It describes both a process of primarily economic development and, in a wider sense, a state of international influence or operation. For the purpose of this discussion we are not interested in the abstract concept; we are reviewing the term from an engineering stand point, i.e. what are the consequences for society. Benyon and Dunkerley (2000) response can shed some light for engineers

> "there is increasing recognition that globalisation and global environmental change pose threats, threats that are the result of powerful economic forces, irresistible technological advance, consumption-led development and the irreversible disruption of environments at the global scale"

4.6.6 Global citizenship, culture and overconsumption

Cultural globalization refers to the homogenization and hybridization of world-wide culture (Allen, 1995). Arguments for the existence of a global culture suggest structural changes of economic globalisation (Waters, 1995). Allen (1995) stated there appears to be a number of globalisations, , taking shape. There is the globalisation of telecommunications, finance, culture, and environmental concerns as engineers we should be concerned with consumerism as it fast becoming normalized as a defining characteristic of the lifestyle of the so-called developed nations the 'west' and, increasingly admired by 'the rest' of the world respectively.

Culture is the principal mechanism through which human - environment interaction can occur (Milton, 1996). The new global culture has been characterised as an extrapolation from recent western cultural experiences of postmodernism (Smith, 1990).The foundations of the current western industrial and economic models are based on consumption of natural resources.

To simplify this complex relationship between environmental impact, population growth and over consumption, let us review factors identified by Ehrlich and Holdren (1971)and later modified by Dietz and Rosa(1994);

$$I = PCT \tag{4.8}$$

Where,

P= population
C=consumption
T=technology

Over consumption in a consumer society is a worrying sign for engineers as we are the important link in the chain, supplying and converting natural resources to feed the overconsumption habits. Whether we call it westernization, Americanization, McDonaldization (Ritzer, 1993), McWorld (Barber, 1996), any way we dissect it appears to resemble cultural imperialism or corporate colonization.

> "Although the interconnectedness of the earth's ecological systems and their ties to the global marketplace have been broadly established, there is no effective forum in which parties can engage in a sustained and focused dialogue, identify priorities, and devise common action plans to manage these linkages systematically. Decisions with serious environmental repercussions are undertaken within the structures of the economic, finance, and trade institutions, where short-term economic priorities often trump long-term visions for sustainability"(Esty, 2002).

4.7 The profession from my own perspective

Present-day thinking has led from previously-accepted practices such as end of the line measures for example, where diluting the pollutant or dumping it in a sufficiently remote inaccessible place was acceptable; whereas nowadays, products and systems are designed to prevent or minimise the pollutants. (Sikdar, 2007b, 2007a) reports on four types of tools needed for building th sustainable systems. Depending on the scope of an objective, one of the four or all four types might be employed in designing cleaner technologies. These are:

1) metrics tools; for measuring progress towards sustainability,
2) analytical tools; for problem identification, problem analysis, and decision making for design,
3) process tools; for designing unit operations and processes, and
4) economic tools; for assessing the incentives for cleaner practice.

The scope of this research will limit discussion on items 3 and 4. The changing nature of the profession is highlighted in a simple example of past and present trends in product development, as shown in Figure 4-21, where priority has shifted from the consumer to satisfying the management of natural resources. Gone are the days where the motor industry used to promote the petrol guzzling 5 litre V8's rather than economic new-age, fuel efficient 1.5 litre motor vehicles.

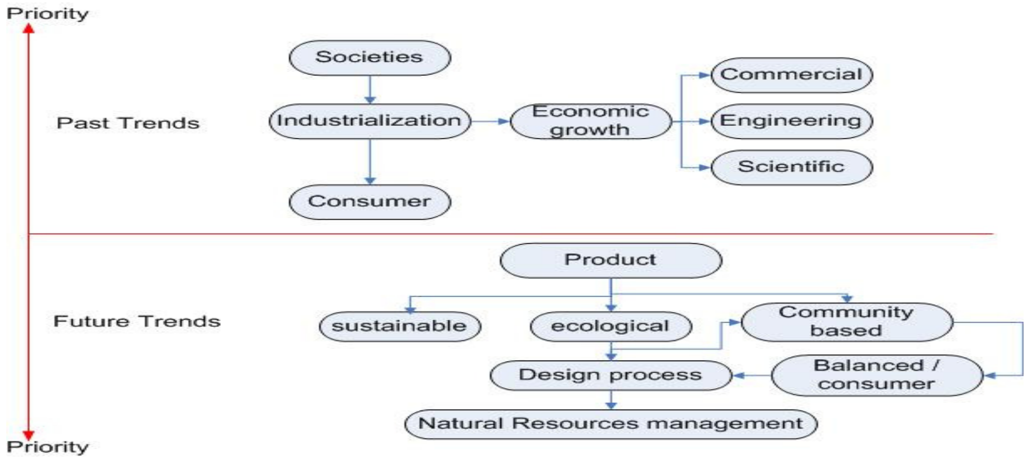

Figure 4-21: Past and future trends in engineering designs (Hasna, 2009a)

According to Einstein,
"Problems cannot be solved by the same level of thinking that created them."

Hence, unsustainability tribulations attributed to the "old" engineering philosophy cannot be deciphered using "old" engineering thinking. Similarly a "new" sustainability engineering model cannot be derived from the "old" principle. The momentum towards sustainable practices in engineering has been building nationally since the Intergovernmental Agreement on the Environment (IGAE) which was signed by the Heads of Australian Governments in May 1992. Yes the industry and profession are changing, but the current climate is an opportunity to apply new practices.

Just as economic considerations are typically an integral part of any engineering design and a force for refinement sustainability ought to be viewed in a similar mindset, a desire to keep the process, product or service sustainable to resemble safety factor calculations to cover uncertainties of a design in the real world. . Overall , the engineering profession has changed as a whole and in particular chemical engineering there are now numerous sub-disciplines of engineering; during this same period the market has changed significantly (Hasna, 2009b). The last decade, we have witnessed a great shift in engineering culture, especially towards clean and green technologies. Furthermore, with the advent of IEAust Sustainability Character (2007) and IChemE, Sustainability Performa, and AIChE, Waste Reduction Technologies, it appears that the chemical engineering profession has started the discussion and is on course to integrate sustainability into daily practices. Such changes imply the need for a new ethical engineering approach and to safeguard ongoing implementation of these strategies the changes are perhaps out to be dealt with at engineering education level.

4.8 Conclusion

> "Global warming and climate change is of increasing concern, as it is more widely realised that the planet Earth cannot provide an infinite capacity for absorbing human industrialization in the 21st century.." (Hasna, 2009f),

The analysis presented a case in support of the “engineer’s” involvement in developing sustainable practices. The importance of natural resources to the Australian engineering industry was demonstrated through the two case studies. The contribution of these two sectors to Australian economic development was evident with the GDP figures. Engineers need to have an understanding of the “pivotal role” they play so that they will be able to design products and systems that integrate sustainable engineering practices. This was confirmed by the significance of energy efficiency through the case study analysis. The role of energy efficiency in society is colossal as it determines the real output or productivity of engineering technology. For example, the 46% drop in U.S. energy intensity (primary energy consumption per dollar of real GDP) during 1975–2005 represented, by 2005, an effective energy “source” 2.1x as big as U.S. oil consumption. The conclusion of the design process analysis listed in Table 4-4 demonstrates technical efficiency.

	Power plant	**Pump system**	**Microwave oven**
Efficiency	44.2 % from primary	9.5% from primary	44 % from secondary

Table 4-4: Efficiency summary (Hasna, 2009d)

Chapter 5. Engineering Design and Sustainability

5.1 Outline

This chapter investigates engineering design to advance the goal of sustainability as per the definitions discussed in Chapter 2. This will require looking at engineer's role as problem solvers, reviewing the existing design strategies and framework in order to determine an appropriate method to incorporate sustainability factors as explicit performance criteria. In addition we plan to review sustainable design software. This chapter aims to combine design parameters with design engineering sequences to incorporate sustainability all facets of in the engineering design process.

5.2 The engineering design tradition

In an increasingly designed world embedded in our physical, psychological, economic, and social environment, good design is the means to improving this world through innovative, products and services, creating value, and reducing or eliminating the negative unintended consequences of technology deployment. Our society has become dependent on technology in recent years; the rapid developments in technology have provided many benefits, and give rise to a number of associated problems (Wallace and Clarkson, 1999). The word 'design' has several connotations across engineering disciplines and for this reason perhaps that different understandings exist. Societies demands of design change over time.

> "Industrialization required the abandonment of traditional design methods and a move to the drawing board and mathematical models" (Beder, 1993a).

Most literature agrees that engineering design over the past two hundred years has been markedly different since it consisted of a significant portion of trial and error.. Thus, traditional methods and modern methods are distinctly differentiated. traditional designs, were culturally fixed traditions rather than based on science or engineering (Alexander, 1970). Today design methods are changing with the changing requirements of industrialisation according to their cultural context, with the aid of computer aided graphics the designer can achieve in one hour of solid modelling what previously took years to design.

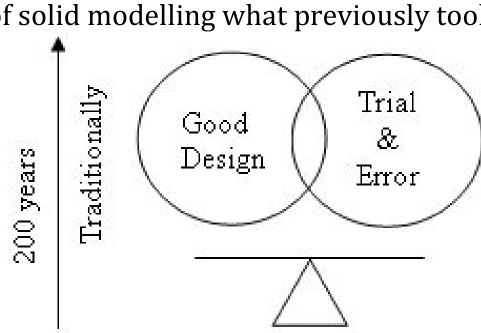

Figure 5-1: Evolution of engineering design

Today at the highest level, chemical engineering design can imply a project design which incorporates all aspects of designing a plant, from concept to commissioning of the project. On the other hand, this encompasses many other engineering disciplines. At the lowest level, design can imply equipment design by sizing equipment to its potential application. The sizing of equipment such as reactors, heat and mass transfer units, pumps and compressors are typically included in the mechanical design of equipment.

5.3 Engineers as problem solvers

To understand how engineers take the role of problem solvers let us review the mechanisms of decision making. What constitutes it? There are many decision-making processes described in behavioural and scientific literature along with many real-world applications to which they have been applied. Koontz (2007) is defined decision-making as the selection of a course of action from alternatives. The simple route decision-makers use is indicated in Figure 5-2, These processes mature with age and experience and are influenced by acquisition of knowledge. Other influencing factors include cognitive, psychological, social, cultural, and societal factors as presented in Figure 5-3.

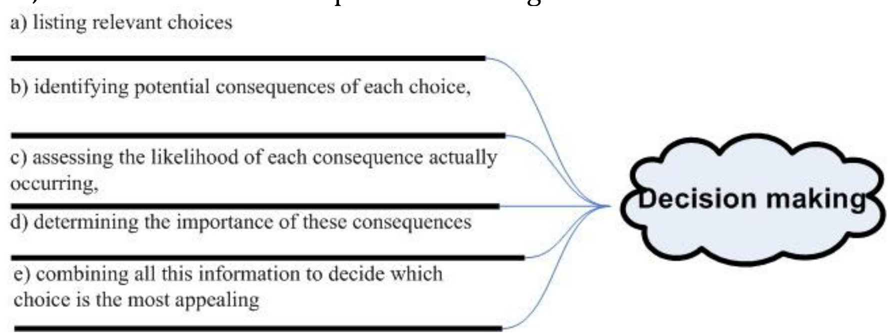

Figure 5-2: Sequences in decision making (Hasna, 2008c)

People are not alike and nor are engineers. (Turban, 2001) indicates that there is strong relationship between personality and decision-making. Personality types influence general orientation toward goal attainment, selection of alternatives, treatment of risk and reaction under stress.

> "Because of the nature of their work, engineers tend to work at the site or project level" (Donnelly and Boyle, 2006).

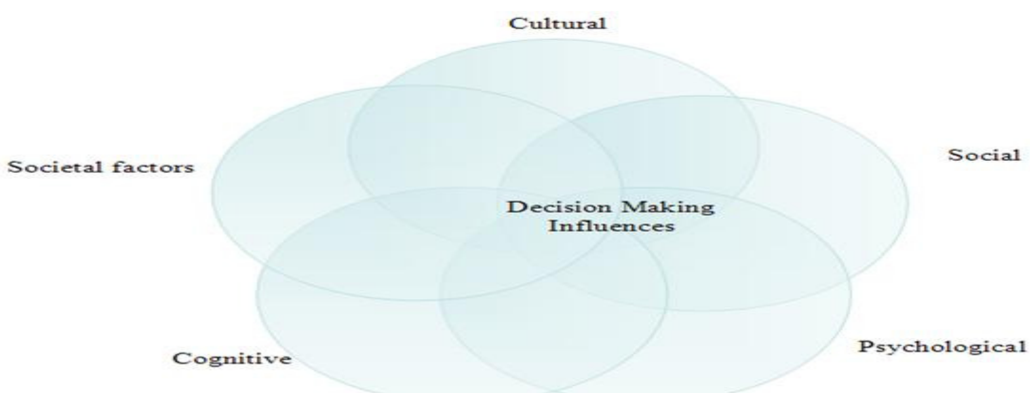

Figure 5-3: Influences of decision making (Hasna, 2008c)

Given that problem solving has been the traditional role of the engineer , and, to a large extent, this is the role that most engineers fulfil today working within confined boundaries (Donnelly and Boyle, 2006). Engineers need to look beyond the problem as it is presented to them McDowall, (1999). In reality the engineer on site or plant is an employee paid to perform a job. Hence, unable to address sustainability or take out any action required to eliminate or reduce. Whilst the local site/plant level is important to decision making however sustainability initiative needs to be supported from top management to consider integration of the larger system as well.

5.4 What is engineering design?

> "Design is the term commonly used today to describe the invention, planning, and realization of both tangible and intangible products, including all of the digital products that now exist alongside traditional analog products"(Buchanan, 2001)

The word 'design' has its roots in the Latin "designare", meaning to designate, to outline, plot or to conceive or contrive(Mitcham, 1995), it is everything you do when you don't know what to do next (Jakiela, 1990),it is a fundamental purposeful pervasive and ubiquitous activity (Banerjee et al., 2008). According to Voland (1999) "It is an innovative and methodical application of scientific knowledge and technology to produce a device, system, or process, which is intended to satisfy human needs".

> "Engineering is the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of humankind" (Landis, 2000).

Engineers Australia Accreditation Board defines engineering design as proficiency in employing technical knowledge, design methodology, and appropriate tools and resources to design components, systems or processes to meet specified performance criteria (Engineers Australia, 2008). Similarly, in the USA, the Accreditation Board for Engineering and Technology (ABET) defines engineering design as "the process of devising a system, component or process to meet desired needs (ABET, 2003).

> "It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective"(BMED, 2001).

In reality engineering design is not as formal as per the classical definition, engineers carry a heavy responsibility since their ideas, knowledge and skills determine in a decisive way the technical, economic and ecological properties of the product (Pahl and BeitzW, 1996).

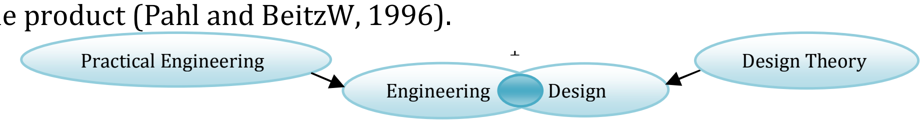

Figure 5-4: The engineering bond

On the other hand engineering Design is the process of applying various techniques and scientific principles for defining a useful device, process or a system in sufficient detail to permit its realization. Simon (1997) pointed out anyone who formulates programs of action to change an existing state to a preferred one is actually designing. According to Pahl and Beitz (1996), the main task of engineers is to apply their scientific and engineering knowledge to the solution of the technical problems, and then to optimise those solutions. Furthermore engineering design is not exclusive to engineers an important foundation noted by (Simon, 1996) is that "schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design".

5.4.1 The engineering Design process EDP

The EDP is defined as the systematic, creative, iterative and often open-ended process of conceiving and developing components, systems and processes. Furthermore the design process and design outcomes are subsystems of the whole engineering system, whose objective is the fulfilment of a defined need as shown in Figure 5-5 (Ulrich and Eppinger, 2000).

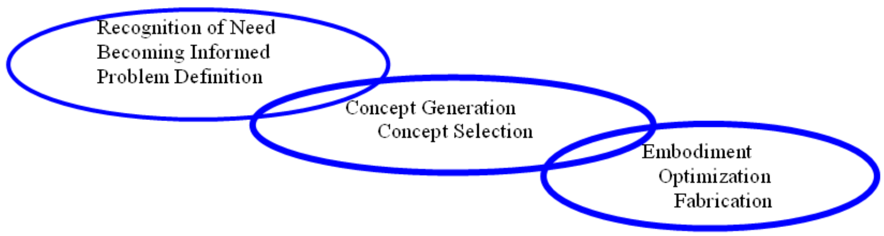

Figure 5-5: The Design Process (Ulrich and Eppinger, 2000)

The standard Design process, in its most general framework is presented in Figure 5-6, important to this discussion, However, in reality it is seldom so straightforward and in most cases, it corresponds more to a design spiral (Sen and Yang, 1998) where the requirements of design are met incrementally until some compromising design criteria have been met.

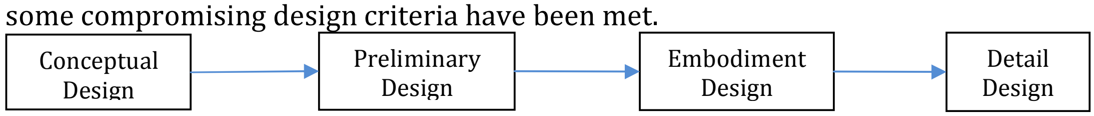

Figure 5-6: Simplified model of design process (Pahl and BeitzW, 1996)

On a more general level, design consists of a loop that requires creativity: product design, manufacturing, marketing, improvement, and product design (Suh, 1990) as presented in Figure 5-7 and Figure 5-8. As commonly practised, engineering design could be loosely classified as follows: Design by code - where conservative rules of thumb predominate; or Design by analysis - where fundamental engineering science predominates (McGowan, 2000).

Creative Design	The key element in this design type is the transformation from the subconscious to conscious.
Innovative Design	The decomposition of the problem is known, but the alternatives for each of its subparts do not exist and must be synthesised.
Redesign	An existing design is modified to meet required changes in the original functional requirements.
Routine Design	Involves finding appropriate alternatives for each subpart that satisfy the given constraints.

Table 5-1: Level of creativity in design

Gero (1990) explains creativity in design as the design variables and the ranges of values they can take remain fixed during design processing. Then the process is routine design; problem formulation and reformulation. The level of creativity involved in design can be classified into four categories listed in Table 5-1(Bahrami, 1994).

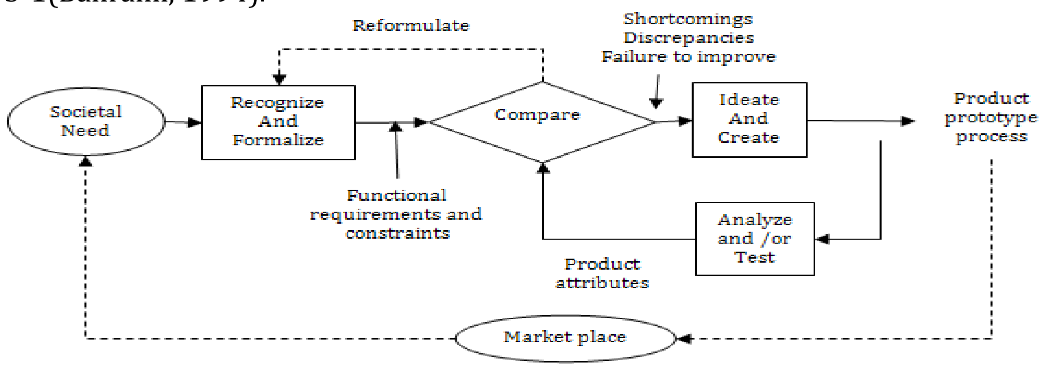

Figure 5-7: The design loop (Cvetkovi´c, 2000)

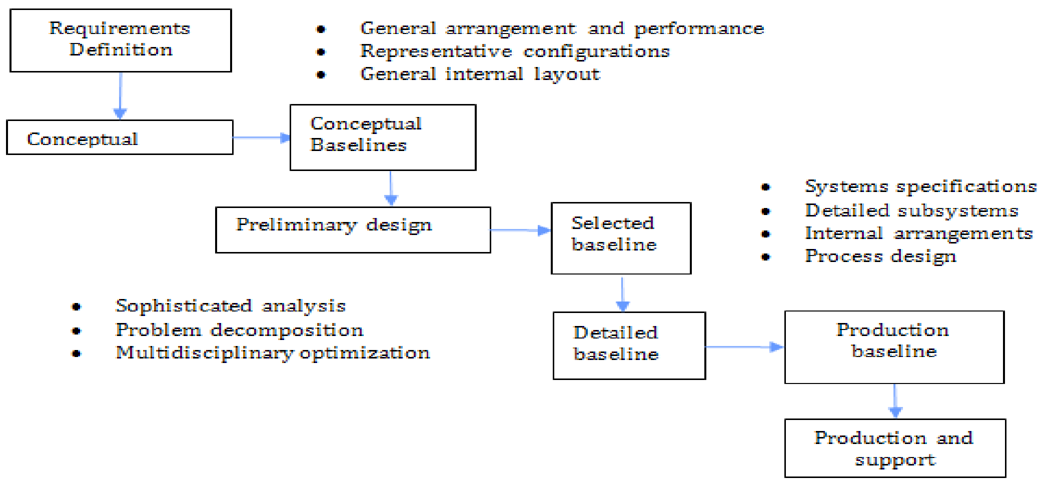

Figure 5-8: Typical design phases (De Weck 2005; Jones, 1980)

The design process is iterative to achieve final design, as stated by several authors (Cross, 1994; Hubka and Eder, 1996; Roozenburg and Eekels, 1995; Smith and Eppinger, 1997). An iterative model of a basic design process is presented by, for example, Roozenburg and Eekels (1995) depicted in Figure 5-9. This iterative design process could be found within each of the three later phases of the phase type model.

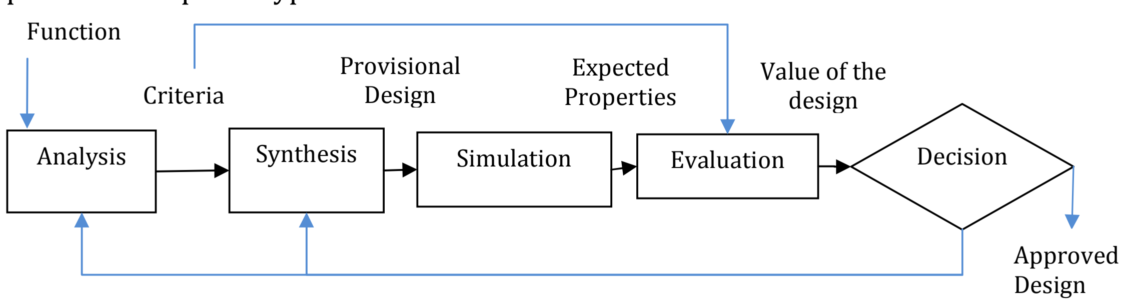

Figure 5-9: The basic design cycle (Roozenburg and Eekels, 1995)

According to AS/NZS 9001:1994 for architectural and engineering design practices shown Figure 5-10 represents a simplified diagram of the relationship between design review, verification and validation. This standard requires documentation procedures be established and maintained. However, it does not require these procedures to set out how to design.

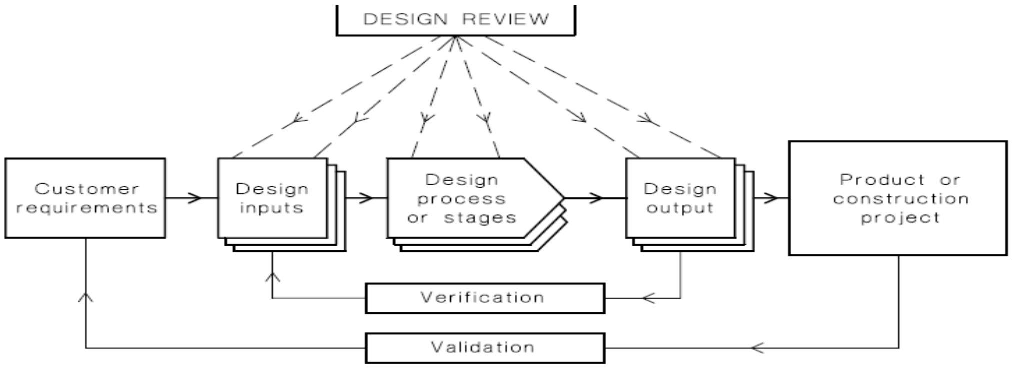

Figure 5-10: Quality standards in engineering design relationships (AS/NZS 9001, 1999)

While engineering design problems differ in scope and capacity, typically a generic process is used to solve them. A summary of the design process steps is listed in Table 5-2. The design function in engineering design is best described by the following quote:

> "Problem solving is common to all engineering work. It may involve quantitative or qualitative factors; it may be physical or economic; it may require abstract mathematics or common sense. Of great importance is the process of creative synthesis or design, putting ideas together to create a new and optimum solution" (Engineering, 2009)

Research	Using mathematical and scientific concepts,
Development	Creative application of new knowledge
Design	satisfy technical requirements
Construction	determine procedures
Production	choose processes and tool
Operation	control machines, plants, and organizations."
Management and other functions	analyse customers' requirements,

Table 5-2: Design process adopted from (Engineering, 2009)

5.4.2 Design strategies

The term 'design strategy' is used to mean a list of actions taken by a designer, or by a planning team, in order to transform an initial brief into a final design. The following section presents the various strategies available.

> "Different societies at different times had required different design methods, concepts and regimes."(Beder, 1993a)

Ideally pre-planned strategy is linear, being composed of a sequence of actions. Each action is dependent upon the output of the last but must be independent of the output of later stages, as shown in Figure 5-13.

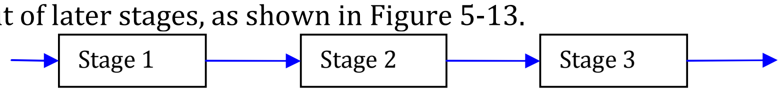

Figure 5-11: Linear strategy adapted from (Jones, 1980)

The transformation of the liner strategy occurs once an earlier stage has to be repeated after the output of a later stage becomes known, this strategy becomes cyclic. Sometimes, there will be two or more feedback loops nesting inside each other, as in Figure 5-12.

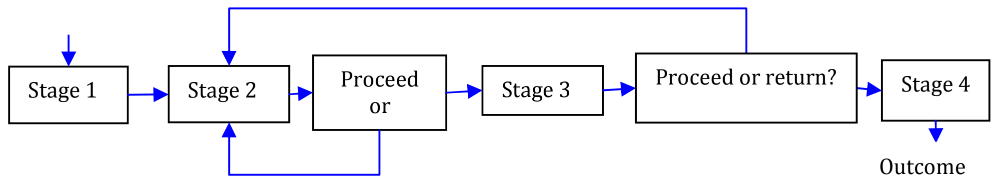

Figure 5-12: Cyclic strategy adapted from (Jones, 1980)

A branching strategy occurs once design actions are completely independent of each other, shown in Figure 5-13. Adaptive Strategies as shown in Figure 5-14, begins with the first design action only. The choice of each phase thereafter is influenced by the outcome of the previous achievement (Jones, 1980).

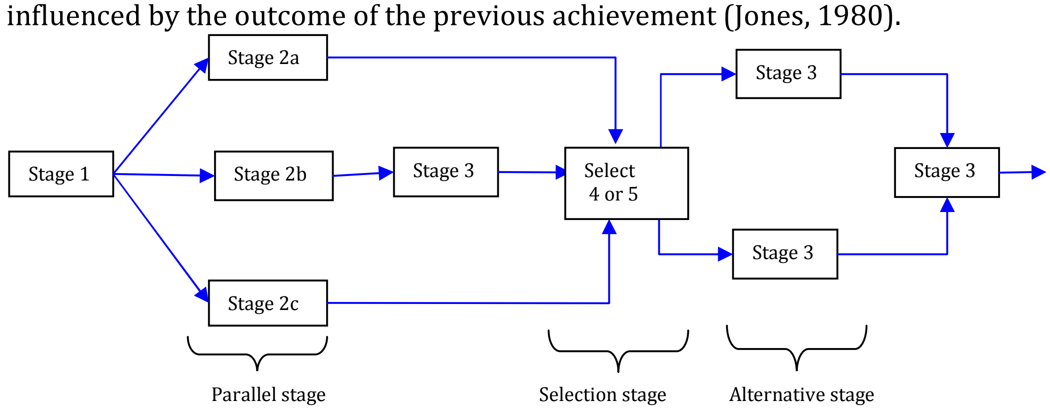

Figure 5-13: Branching strategy adapted from (Jones, 1980)

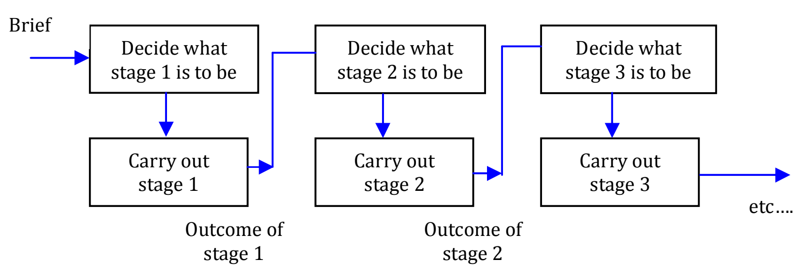

Figure 5-14: Adaptive strategy adapted from (Jones, 1980)

5.4.3 EDP Critique

The reviewed EDP more or less pigeonholed the engineers to robotic answering questions type role, to identify the problem, to collect information, to interpret information, to organize a needs' hierarchy, and finally to determine the relative importance of needs. By and large the all the reviewed EDP confine the engineer to a discipline boundary it has been reviewing processes and outcomes. However this philosophy fails to address sustainability in the concept generation stage of the design consequently fails to identify sustainable opportunities. This is the shortcoming of the existing EDP, which also highlights that engineers are lacking a devised sustainability method in EDP. We need to modify the existing rudimentary engineering design process to repair the extensive damage that the development paradigm has wrought upon on the environment and society, the motivations behind this philosophy are as follows;

- Officially integrate the design approach
- Stop the philosophy of environmental protection and conservation practices, and

- Design towards net positive outcomes, rather than minimizing negative impacts on the environment and society.

5.5 Available software modelling tools

To achieve a comprehensive understanding of engineering design processes and its possible adaptability to sustainable practices it would help for engineers to have sustainability be included in design software. At the time of research there were no integrated design tools hence this section reviews sustainable design through life cycle assessment LCA software modelling-simulation tools available. When reviewing the–different software available, it is important to find a package that is easy to operate and will work effectively with the design process. Hence, the review considered the following criteria: compatibility must have supporting literature and demonstration versions of the software available. Jonbrink et al. (2000) conducted a thorough survey of LCA software tools on the market. In this section we will only review four LCA software packages SimaPro, LCAiT, Umberto and GaBi3v2 due to engineering relevancy.

5.5.1 SimaPro

SimaPro is an extensively known package in the chemical and process industry originally developed by Pré Consultants B.V. in the Netherlands. It is widely cited in literature to name a few desalination (Raluy et al., 2004), fermentation (Manish and Banerjee, 2008), emissions calculation(Portha et al., 2008) , refining (Jiménez-González and Overcash, 2000), Green diesel production (Kalnes et al., 2008). The demonstration version is available on the company's website; it can be easily downloaded with complete help manuals. Upon running the software easy to use and required little effort. The software has an accompanying database including energy, transport, processing, waste treatment, packaging materials, materials. It has a data import feature. In addition 'code' based macro programming. The current price for SimaPro 7.1 professional versions is 4200 EUR and further databases can be purchased at a later date.

5.5.2 LCAiT

LCAiT software was developed by Chalmers Industriteknik CIT Ekologik Sweden as an LCA Inventory tool for the environmental assessment of products and processes, examples in literature include sewage sludge (Svanstrom et al., 2004), furnace slag(Lee and Park, 2005), heat distribution system (Froling et al., 2004) and buildings (Lee et al., 2009) . It includes an energy database and more databases can be purchased separately. It has an import and export feature using the SPINE format. The standard software LCAiT 4.0 general license costs 3800 EUR, chemical and other modules are considered as extras.

5.5.3 Umberto

Umberto 5.0 is the current version of a software-tool developed by the Institute for Energy and Environmental Research Heidelberg Ldt (IFEU) in co-operation with the Institute for Environmental Informatics Hamburg Ldt (IFU) Germany. Umberto is an Environmental Assessment System which offers analysis of material and energy balances, and a systematic hierarchal process analysis, from plant floor up to cooperate offices for product process and process chain input, It took a good part of 1 hour to start it has specific modules for energy, materials and chemicals. mush less citation in literature Chemical industry (Benetto et al., 2009), material flow analysis (Brunner and Rechberger, 2004). Overall all the useability was difficult and time consuming. Umberto 5.0: Business Professional License costs 5 925 EUR.

5.5.4 GaBi

The GaBi software family, for Life Cycle Engineering, was developed by the Institute for Polymer Testing and Polymer Science (IKP) 2001 at the University of Stuttgart. Whilst the software has superior built in features, its useability was low due to its complexity. The database system includes data sets for metals, many plastics, electronic components, construction materials thermal energy and steam, natural gas, biofuels, fuel oil, etc from the Institute for Environment and Sustainability. literature was limited on pure chemical engineering modelling, except for one LCA on telecommunication products (Scheller and Hoffman, 1999). The software was offered in two forms Gabi lite, and GaBi 4 pricing was not available

5.5.5 Software conclusions

All of the Life Cycle Assessment (LCA) software package tools reviewed offer similar baseline features. The range of sustainability software available can only be found in the form of LCA tools; it stretches from highly technocratic tools to very simplistic methods. This diversity of the LCA software tools on offer making it necessary to be an LCA expert to firstly test drive. Typically results are presented in either one of the following classes: 1. Technical language that seems to require vast scientific and technical efforts to unpack, 2. Oversimplified to a few summary statistics. Finally these tools, do not offer the engineer with the knowledge to design for sustainability. On the other hand, there are other assessment processes ranging from a variety of 'assessment', derived from environmental impact assessment and an extended form of strategic and general environmental assessment to incorporate 'triple bottom line' approach social economic and environmental considerations Figure 5-15 lists the results of the survey. 21 software packages were found.

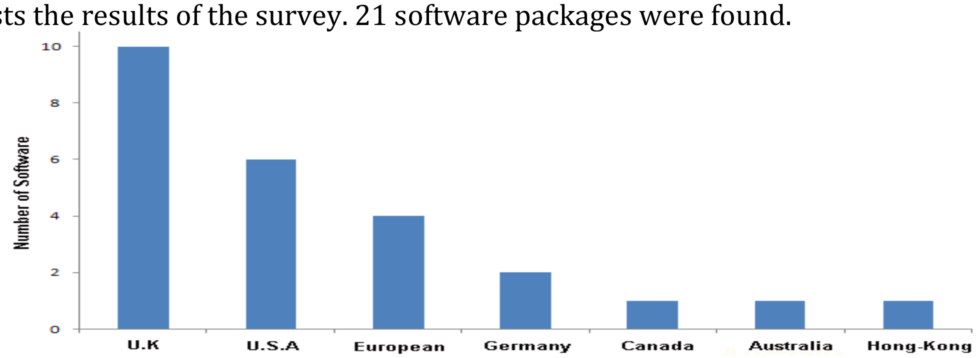

Figure 5-15: Sustainability software by country

5.6 The Engineering project and project management (PM)

The generic phases of an engineering project include a technical pre-feasibility and feasibility study. The feasibility study usually contains a detailed return on investment, bottom line financial analysis, detailed engineering design, project scheduling and commissioning analysis. The design stages involve complex mathematical procedures to refine and optimise. Typically the designs are required to perform precisely defined functions for a specific length of time; sometimes engineers design technology to be rendered redundant. The design procedure is a transformation process; this transformation from inputs to outputs is an iterative process.

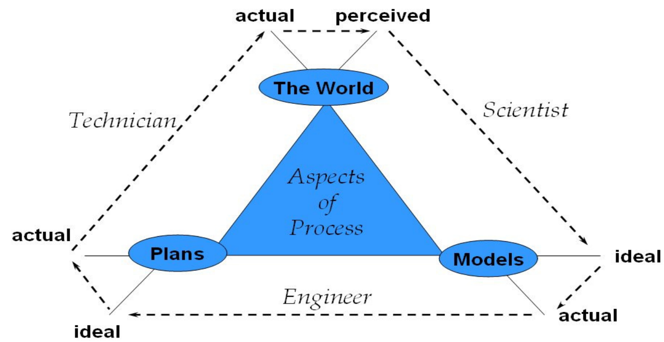

Figure 5-16: Organisation process

5.6.1 PM software survey

A project is a unique endeavour typically divided into individual activities which are linked by precedence relationships (Mellentien and Trautmann, 2001). Project planning is largely made up of temporal scheduling, resource allocation, and cost management. Project planning problems arise, for example, in software development, in engineering, in production planning or in audits. Different commercial software packages are available for computer–aided project management. In this thesis, we reviewed performance analysis of the resource allocation modules implemented in the following software packages; Acos Plus.1 8.2 (Acos), CA SuperProject 5.0a (Computer Associates), CS Project Professional 3.0 (CREST Software), MS Project 2003 (Microsoft), and Project Scheduler 8.0.1 (Scitor). From our basic review, it was found that no one software package is designed to consider general temporal constraints between activities and hence would not be suitable for a design engineer to assign sustainability criteria.

5.7 Proposed Sustainability in engineering design process EDP

It is no hidden secret that the engineering industry as a whole is moving towards the mitigation or avoidance of environmental damage and to consultation with those who may be affected. Overall goal of sustainability in the EDP is to translate sustainable requirements into plans, evaluations and specifications, once implemented, meet the design objectives and satisfy specified constraints. Usually this synthesis takes place in the idea generation stage. The literature review in section 5.4.1 page 5-94, presents repetitive patterns of EDP, with sustainability being the missing link. This section presents the modification of EDP and responding to the critiquing of the previous section.

5.7.1 Characteristics of Sustainability in engineering design process

According to Moody et al. (1997), attributes of a good metric, should measure aspects of the process that can be controlled; provide information that can initiate change; show how well goals are being met; be simple, understandable, repeatable, and measurable; and have inexpensive methods of data collection.

"that it should be remembered that forecasts often turn out to be wrong and that evaluation criteria depends on values. Values differ, both between cultures and between individuals. Selecting the best course of action in any design situation is therefore difficult and depends on information availability and the viewpoint of the decision maker. It is equally important to note that not all systems are designed; for example, Velcro was invented, not designed; the internet grew and was not designed"(Wallace and Clarkson, 1999)

(Lyytimaki and Rosenström, 2008) provide an analogy with skeletons and sustainability frameworks.

"Different skeletons and frameworks provide different possibilities to react to pressures caused by the environment. An external skeleton gives good protection and support, but it allows only limited possibilities to adapt"

Considering EDP with the aforementioned it would be important to combine Moody et al. and Wallace and Clarkson comments into mentioned characteristics in any potential design method. Hence the proposed values in this model rely on replacing end pipe methodologies in the engineering design process to design for net positive outcomes in this transition towards achieving sustainable engineering practices. Whilst it is not a startling observation, it has not been publicised in literature. Therefore, sustainability needs to be placed at the initial phase of the rudimentary engineering design process rather than an added-on extra or bolt-on feature.

5.7.2 Proposed EDP methodology

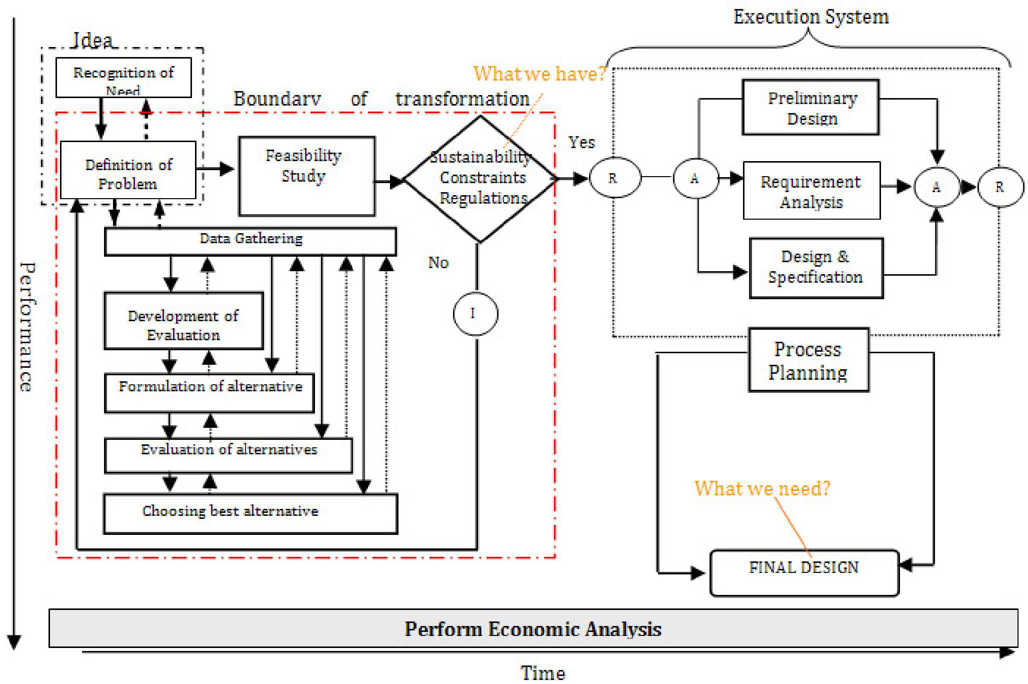

Figure 5-17: Engineering design process with sustainability (Hasna, 2008c) where I – Iterate, R- Replicate and A –And

The proposed framework for sustainability in EDP is shown in Figure 5-17 offers generic steps to be used points of reference towards a net positive outcome. This achieved by assessing the design ideas against sustainability indicators (checklist). On the whole, the designer begins with the idea generation, this is located at above the boundary of transformation this where the idea is analysed against sustainability constraints similar to Table 5-3 and Table 5-4.

5.7.3 Case study: undergraduate engineering students

The basic purpose of this design process was to allow student designers to exercise technical decision making with social responsibility. The EDP evaluation matrix shown in Figure 5-17 was used by a group of second-year undergraduate engineering students under the author's supervision to conduct a preliminary design project titled "Hot Dry Rock System to generate 1MW of Power (Hasna, 2008b).

Initially, the students were advised to use the idea generation and boundary of transformation phases to probe the boundaries. Probing the boundaries sets the idea (approximation) free to be considered in global context. Highlighted in the dashed lines are the sustainability examination zones as shown in Figure 5-17. For example, students were advised to choose a concept and check if it satisfies the design brief for "sustainable practice" otherwise keep trying new ideas or modify the concept by checking it values against the design parameters. The students were learning that in order for design ideas to be considered sustainable, the ideas must pass through the indicator check list Table 7-2.

For example, how sustainable is the proposed idea? Short term ? long term? Net positive outcome? This concept was applied through a sequential process for their design course using the criteria in Table 5-4, to provide interactions of those ideas within the entire systems (global context). It was a process of guided redesign of ideas; while synthesis was considered by some students as the "exciting" aspect of EDP. Students began to communicate their perspective and ideas for this design, demonstrating social awareness of engineering designs whilst ensuring that all the proposed designs satisfied the technical constraints. The students reported a positive experience of humanization of technology by matching the needs of the user for the culture and economics.

The author had explained to the students to reflect on real world engineering design, since it is more often based on modification of existing designs or selection of standard components (pumps, heat exchangers, drives, gears, bearings, etc.) than on radically innovative concepts. In summary, this particular exercise provided a rudimentary framework for sustainability consideration at the initial stages of a given engineering design. The proposed EDP allowed consideration of sustainability in design, resource management, economics and ecosystem management, hence developing literacy in calculating and understanding the true economic and environmental cost of development.

Economic	***Environmental***	***Societal***	***Political***
Direct	*Material Consumption*	*Quality of Life*	*Socio-Politics*
Potentially	*Energy Consumption*	*Peace of Mind*	*Equity*
Contingent	*Local Impacts*	*Illness*	*Credit*
Relationship	*Regional Impacts*	*Accident*	*Transparency*
Externalities	*Global Impacts*	*Health*	*Employment*

Table 5-3 : Typical sustainability themes and components

Dimension	Global	National	Local(Project)
Economic	GDP	Trade	Employment
	GDP/capita	Taxes	
Environmental	GHG emissions	Biodiversity	Local air quality
	Biodiversity	Air quality Water quality	Local water quality
Social	HDI	Employment	Health /Capacity building
		Poverty reduction	Community participation

Table 5-4: Some sustainability indicators at different levels (Saleem, 2002)

5.8 Conclusion on sustainability in design

> "It has been widely acknowledged that established design approaches with its standards, rules and guidelines, falls short with respect to issues relating to the cultural context"(Shen et al., 2006)

The reviewed literature has highlighted the absence of sustainability criterion in the engineering design process. To confine the engineer to the role of "problem solver" only will not be adequate to deliver sustainability; engineers need to be involved in what is happening outside their immediate professional boundaries. This is required to ensure that when an engineer arrives at a good solution, the impacts of that solution are considered in a global context. To accommodate 'problematising the problem' meaning not to just take the problem as it is, but to ask 'why is that problem there? What is the problem of the problem? (Long and Failing, 2002). This theory is more relevant in the backdrop of energy efficiency analysis in case studies results presented in previous chapter.

Sustainability is not simply a technical concept or an implicit property although engineers will need to play a key role in achieving its technical demands. Global sustainability needs to be taken up as an important design criterion (Johnston, 2001). The development of engineering design guides for sustainability requires a systems treatment (Cutcher et al., 2004).

Engineering Decision-making processes will always encompass some degree of uncertainty and risk, particularly in the state of natural systems (Dovers and Handmer, 1995). Currently we address these uncertainties through a variety of tools and precautionary measures such as indicators and risk assessment. Therefore, the proposed design process with sustainability is a fundamental change in philosophy, it is a non-linear process, and it is driven by internal values instead of compliance in response to imposed requirements. This requires a multi-disciplinary approach to decision making, consideration of long-term sustainability over short-term benefits and conservation objectives incorporated into design criteria. This chapter aligns true with the thesis of this dissertation a discussion on sustainability in engineering, rendering the need for sustainability to be included in the initial phase of the design process rather than an added on extra in the final stage of the design process.

Chapter 6.
Laws of Thermodynamic and Sustainability

6.1 Outline

It is difficult to work in cohesion if we do not have a contextual engagement and common understanding of the system we are attempting to sustain. To completely appreciate sustainability, we need to zoom out above the local/international perspectives. Let us visit system theory to assess the planet as a closed or open system. For instance, any person, group or nation needs to consider how their sustenance is achieved and on which basis they may assure their well-being, i.e. by interaction with other dimensions i.e. natural resources etc. This raises a primary meaning from a thermodynamic and epistemology point of view, to draw parallels between the exploitation of nature by human society and ideologies and practices of closed/open based on asymmetries. This chapter argues that sustainability philosophy must consider thermodynamic principals as well as include time as a factor as it governs our daily lives.

6.2 The celestial view

The discussion of how to define sustainability is not new neither is literature short on suggestions. The sustainability theory is presented in countless arguments, the most common being journey, process, and organizational; (Assefa and Frostell, 2007; Beder, 1999; Elkington, 2004; Foxon et al., 2002; Fricker, 1998; Johnston, 2003a; Labuschagne and Brent, 2006; McKenzie, 2004; Mebratu, 1998; Sachs, 1999; Sikdar, 2003a).

> "The generally-accepted understanding of the cosmic world with respect to the environmental debate and the concept of sustainability is based on the recognition of the supposedly separate existence of the natural, economic, and social systems. The predominant model in literature shown in Figure 6-1. This model suggests that, as stated by (Holmberg et al., 1996) quoted in (Mebratu, 1998) that the natural, economic, and social systems are independent systems and may be treated independently (reductionist). The interactive zone where the three different systems interact is the solution area of integration where sustainability is achieved, whereas the area outside the interactive zone is assumed to be an area of contradiction (Bivalent)" (Mebratu, 1998).

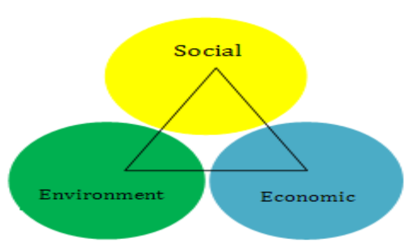

Figure 6-1: Three pillars/triangle of sustainability adapted from (Mebratu, 1998)

However (Martin, 2002; Sverdrup and Svensson, 2002; Sverdrup and Svensson, 2004) have briefly described a systems' thinking approach on the basis that the earth, as a sustainable system, is dependent on the activities of a number of well-defined bio-geo-chemical cycles, and the earth as a sustainable system is open to flows of energy and closed to matter based on the first and second laws of thermodynamics) (Martin and Hall, 2002). These key characteristics are paramount in systems definition of sustainability. For instance, if we consider the sustainability of the planet and the inhabiting sub levels i.e. organisational, national, international and regulatory, it is helpful, therefore, to define it from a system viewpoint so that necessary actions for progress become measurable and achievable. Thus, it would be constructive to think in terms of different systems for which scientific and engineering inputs would be sought and can be envisaged (Sikdar, 2003b). According to (Ewerta et al., 2006), systems theory assumes that no matter how complex or diverse the world is, it will always be possible to identify different types of organizations in it and these can be described by principles, which are independent from the specific issue subject to investigation. An example of hierarchical systems is the biological organisation as commonly used in ecology and environmental sciences with levels such as organism, population, community, ecosystem etc. Figure 6-2 shows a schematic representation of a hierarchical system with fully (white circles) or partially (orange circles) nested sub-systems.

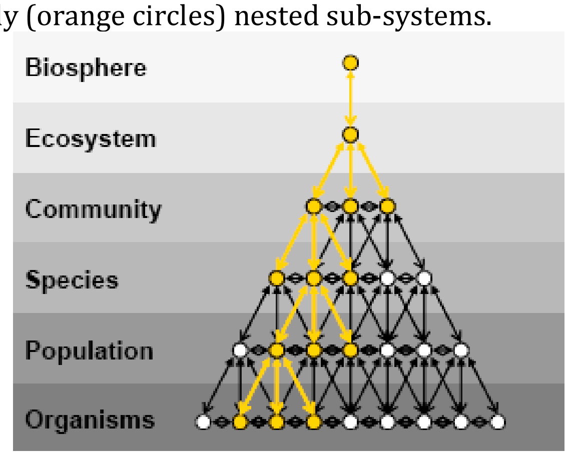

Figure 6-2: Hierarchical system representation (Ewerta et al., 2006)

When discussing sustainability in engineering, it is interesting to consider the Cosmic Interdependence model developed based on the holistic-reductionist-holistic approach.

> "The human universe, never have been, and never will be, a separate system independent from the natural universe. The intersection of the four cosmos is the area where we have millions of combinations of conflict and harmony,. The vehicles of interaction within the interactive zone are millions of systems that do not belong exclusively to one cosmos but have a four dimensional (or three-dimensional, if we place the biotic and abiotic under the ecological dimension) systemic parameter as shown in Figure 6-3. The environmental crisis recorded throughout human history is an outcome of the cumulative effect of deliberate, or otherwise, human neglect of one or more of the systemic parameters. There is an

abiotic region that is essentially free of interaction with the biotic, economic, and social cosmos; and by the same token there is a biotic region that is not yet in interaction with the human universe. However, neither of these regions can be claimed to be free from the second-degree effect of the interactive region" (Mebratu, 1996).

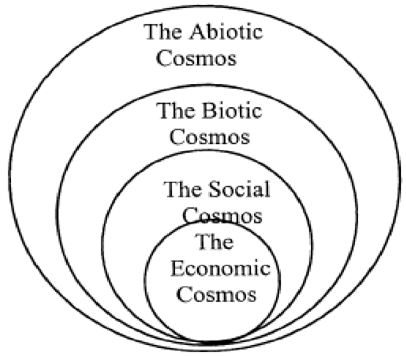

Figure 6-3: The cosmic interdependence (Mebratu, 1998)

According to (Brown and Buranakarn, 2003), all systems recycle.

> "The biosphere is a network of continually recycling materials and information in alternating cycles of convergence and divergence. As materials converge or become more concentrated, they gain in quality, increasing their potentials to drive useful work in proportion to their concentrations relative to the environment. As their potentials are used, materials diverge, or become more dispersed in the landscape, only to be concentrated again at another time and place. Fitting the patterns of humanity to these material cycling pathways has become paramount in importance as our numbers and influence on the biosphere increases"

The diagram in Figure 6-4 illustrates a systematic view of the economic assets development their eventual disposal, and recycling pathways.

1. Environment through landfills or disposed across the landscape.
2. geologic processes through erosion sedimentation,
3. Stockpile of materials used by economic systems, i.e. steel recycle.

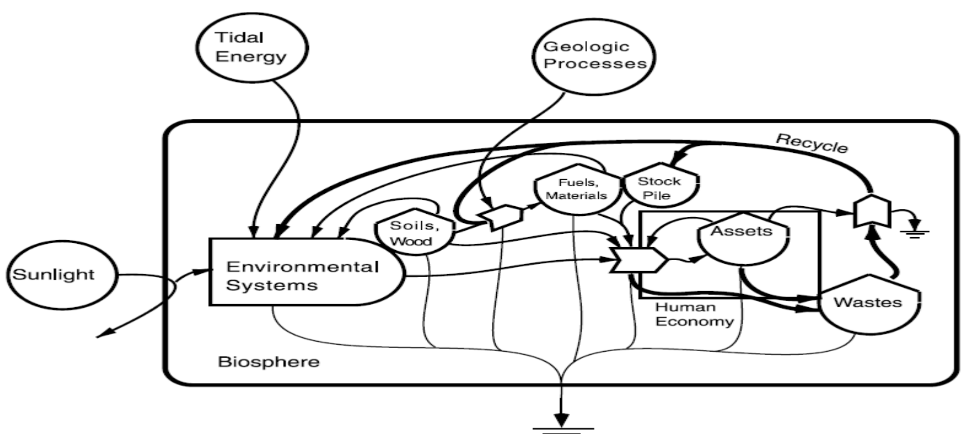

Figure 6-4: The material and energy pathways of the biosphere (Brown and Buranakarn, 2003)

6.3 Laws of thermodynamics

The respective meanings of 'sustain' and 'able', in a nutshell, are 'keep going' and 'can'. The first law of thermodynamics deals with energy. This law is empirical and states that energy (and matter) cannot neither be created nor annihilated; it basically requires that matter and energy be conserved, i.e. matter-energy can neither be created nor destroyed, i.e. the energy content of the universe is constant. Although energy and resources taken from nature may change form, the total amount remains constant and will eventually return to nature as waste or pollution (Boyd, 2005).

$$\Delta \text{ (energy of the system)} + \Delta \text{ (energy of surroundings)} = 0$$

From a sustainability perspective, this law of energy conservation seems to present good news. That is, if the total amount of energy is constant, why should the human race be frugal in using it? The bad news is that interactions between a system and environment always go in a certain direction, a direction in which the energy that is available for performing work continuously decreases.

> "Theories of quantum physics relate specifically to the natural phenomena. hence all phenomena at all levels of organization are interconnected, and thus, all things true at the atomistic level are true of all higher and lower levels of organization"(Ikerd, 1997a).

When evaluating the carrying capacity of the "planet Earth biophysical boundaries", we consider the anthropic presence as a subsystem of the whole biosphere, a closed system, exchanging energy but not matter,

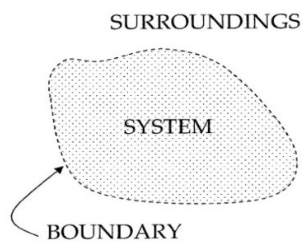

Figure 6-5: System and boundary

The principle of conservation of energy is derived from the first law of thermodynamics which states that energy cannot be created nor destroyed when changes takes place, hence the total energy remains constant before during and after the change, . All energy must come from some source, as Figure 6-6 illustrates with a simple flow chart of solar energy availability into heat energy as an open system. However, if we consider the same process as shown in Figure 6-6 for fossil fuel reserves, the process is treated as a closed system and solar energy has no net effect on the fossil fuel reserve size and volume.

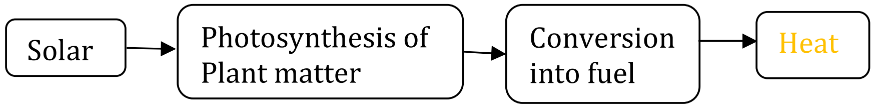

Figure 6-6 Steps of solar energy into heat

The second law of thermodynamics is helpful in understanding the world and its environment. The law describes the direction in which nature unfolds and indicates the difference between a dynamic (=mechanical) and a thermodynamic world view. In a mechanical world, as described, for example, by Newtonian mechanics (Newton, 1687), events (= processes) are solely determined by forces. Such a description allows the process to occur in a reversed direction as well. This is related to the tendency of storing a constant amount of energy in the universe in as many ways as possible. This is the quintessence of the second law of thermodynamics. The second law states that although the total amount of energy in an isolated system remains constant (pursuant to the first law), the quantity of energy in a useful form decreases. In other words, energy always goes from high quality to low quality, decreasing its ability to do work and increasing entropy. This is why you cannot burn the ashes from a fire. The implication of the laws of thermodynamics is that the more energy and resources consumed by society (Holmberg et al., 1996), the more entropy, i.e. disorder in the form of waste and pollution, will be created. In terms of time variation, the mathematical statement of the second law is:

$$\frac{dS}{dt} \geq 0$$

where S is the entropy and t is time.

Entropy is the central notion in the second law of thermodynamics. The entropy of a system is a measure for the number of ways the energy can be stored in that system (McMahon and Mrozek, 1997). Thus, the direction in which events proceed goes along with an increase of entropy. It affirms that every process proceeds in such a direction that the total entropy change associated with it is positive, the limiting value of zero being reached only by a reversible process. No process is possible for which the total entropy decreases (Smith and Van Ness, 1987). Hence, in terms of sustainability, the first law describes that the original inputs may never be recovered from the outputs of real or (more precisely) finite-time processes, and in some cases, from mathematical or infinitesimal-time processes as well. Thus, while the quantity of energy and materials is conserved as predicted by the first law, their quality or availability is not—all physical processes convert low-entropy energy and materials to high-entropy wastes, from which the original low-entropy inputs cannot be recovered without the conversion of still more low-entropy resources to high-entropy wastes. These finite-time processes governed by the second law question the viability of an eternal sustainability theory to our natural ecological system and the survival of humanity. Therefore from the laws of thermodynamics, a system is a region defined by imaginary or physical boundary; the system can be closed or open. The system in which we live in planet Earth is a finite system, and as such, has constraints that are governed by the Physical reality subject to constraints.

> "All physically existent systems are open, having exchanges of energy, matter and information with their environment. Therefore, the behaviour of the system depends not only on the system itself, but also on the factors impinging on the system. Thus, the state of the system at a given time, will be determined by the previous state of the system and by the inputs received by the system in the last period of time" (Gallopín, 1996; Gill, 1969)

The behaviour of a finite state system such as planet earth is given as;

$$\begin{cases} S_{t+1} = F(S_t, I_t) \\ O_{t+1} = G(S_t, I_t) \end{cases} \tag{6.1}$$

The performance of the system is measured by the output variables. Since all the variables vary over time and space. Equation (6.1) can define Sustainability in simple terms:

$$V(O_{t+1}) \geq V(O_t) \tag{6.2}$$

Where:

***V** is a valuation function of the outputs of the system*
***S** is the state of the system,*
***I** is the input vector (the list of all input variables) to the system,*
***O** is the output vector from the system, and*
***F** and **G** are functions*
***t** the subindex stands for time.*

Peacock's(1999) definition of sustainability is that it is purely a matter of the management of scarce and ever-diminishing negentropy. Therefore Sustainable systems will have a tendency towards dynamic equilibrium, not toward some steady state. In addition the second law is widely misunderstood outside thermodynamics as it translates its meaning to growth i.e. all economic activities cause an irreversible process of decay, making fewer resources available in the future. In the words of (Georgescu-Roegen, 1971), the economist who inspired the field of ecological economics, "every Cadillac means fewer ploughshares for some future generations".

6.3.1 Economic sustainability

Economic theory in our society cannot ignore the second law of thermodynamics' where entropy equates to waste of resource and pollution. Any increases in the order and energy flow in certain living systems, produces greater disorder in the environment. Therefore whether economic growth is required to maintain or to improve existing lifestyles, society must ultimately make a sacrifice to lessen overconsumption and invest in renewable to reduce entropy. since low entropy is the ultimate resource which can only be used up and for which there is no substitute (Daly, 1985). Thus, economic viability is a key component of sustainability in engineering. However, the question which needs to be asked is "can we treat "planet earth" as a closed system in our thermodynamic analysis?" According to Rees (1990), the second law states that in any closed isolated system, available energy and matter are continuously and irrevocably degraded to the unavailable state.

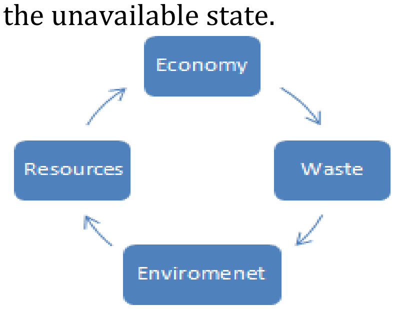

Figure 6-7: The land requirement of an economy

Since the global economy operates within a fundamentally closed system, the second law is actually the ultimate regulator of economic activity. According to this theory this means that from a thermodynamic point of view, all conceivable human activity (even green activities like planting trees and recycling) is ultimately a losing proposition. Since all economic production is in fact consumption. Any form of economic activity dependent upon material resources therefore contributes to a constant increase in global net entropy (disorder), through the continuous dissipation of available energy and matter. Figure 7-2 illustrates the link between the land requirements of an economy where, as far as sustainability is concerned, with the availability of resources i.e. depletion rate should not exceed renewal rates.

6.3.2 Ecological Resilience and Sustainability

Resilience of a system has been defined in two different ways in the ecological literature, each reflecting different aspects of stability (Gunderson, 2003).One definition comprises of efficiency, constancy and predictability, these are all feature engineers' aspire for daily operations..

> "The other focuses on persistence, change and unpredictability – all attributes embraced and celebrated by evolutionary biologists and by those who search for safe fail designs"(Gunderson et al., 2002; Rolling and Marshall, 1994).

In this context, loss of biodiversity, pollution and resource degradation, are detrimental because they increase vulnerability, undermine system health, and reduce resilience (Munasinghe and Cutler, 2007). The concept of ecosystem stability and resilience to are key to symmetrical interpretation sustainability (Bare, 2002) .

> "A system at a given level is able to operate in its stable (sustainable) mode, because it is protected by slower and more conservative changes in the super-system above it, while being simultaneously invigorated and energized by faster changes taking place in sub-systems below it" (Munasinghe, 2003).

An ecosystem state is defined by its internal structure and set of mutually re-enforcing processes. Vigour is associated with the primary productivity or growth of an ecosystem (Dimidia, 2009). Organization of the system is dependent on both complexity and structure. For example, a multi-cellular organism, like a human being, is more highly organized than a single celled amoeba. Thus, according to the second law of thermodynamics sustainability of systems depends on the use of low entropy derived from surroundings, which is returned as (less useful) high entropy energy. Higher states of organization imply lower levels of entropy.

> "The notions of a safe threshold and carrying capacity are important, to avoid catastrophic ecosystem collapse. It is useful to also think of sustainability in terms of the normal functioning and longevity of a nested hierarchy of ecological and socioeconomic systems, ordered according to scale, e.g., a human community would consist of many individuals, who are themselves composed of a large number of discrete cells" (Munasinghe and Najam, 2007).

Therefore ecological sustainability is commonly held in the notion that in order to sustain life on "planet Earth" society must preserve its life-support systems.

This theory is based on the principle that there is an intrinsic "carrying capacity" "planet Earth" that cannot be exceeded without catastrophic or irreversible results to the biophysical world.

6.3.3 Social cultural sustainability

Social and cultural sustainability entails to the distribution of wealth (i.e. intra- and intergenerational equity) in additional it encompasses the environmental consumption of resources and ecosystem. In addition, are legal issues pertaining to property rights, the treatment of common law resources, and the need to consider externalities? The issue may be posed in terms of weak and strong sustainability. Daly and Cobb (1989) discussed divisions between weak and strong sustainability . The distinction between weak and strong sustainability is invalid argued (Common, 1996). Strong sustainability entails that natural capital not be depleted and that humans live off the interest of natural capital. Weak sustainability only demands 'total capital' not be depleted. According to this theory, fish farms might be considered a substitute for wild fish. . Weak sustainability refers to consumption within resources, for example as long as resources have not been depleted it considers it as living sustainably. Elserafy (1996) and Gowdy and O'Hara (1997) offered defence of weak sustainability . According to Assefa and Frostell,(Assefa and Frostell, 2007),

> "One way to characterize a sustainable technical system is to assess its overall system health as a sustainability functioning system. This is portrayed in the form of a ''societal being'' where the processing feature of technical systems represents its abdomen; the function and balance features of ecological sustainability represent its head; and the relevance and context features of social sustainability and the drivers of economic sustainability are the two legs (see Figure 6-8)"

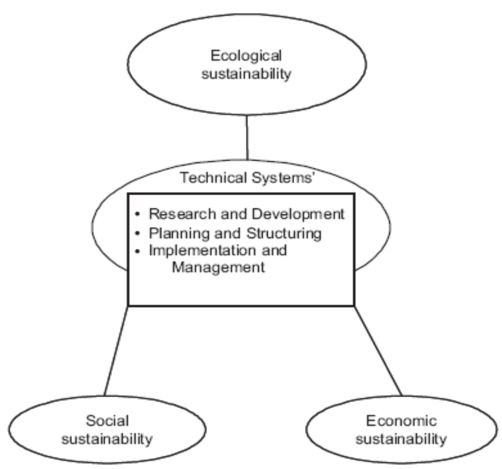

Figure 6-8: Health of a sustainable functioning system (Assefa and Frostell, 2007)

Measuring and quantifying social sustainability for an engineering system to be deemed socially sustainable must reach consensus at minimum it needs to gain a wider social acceptance. Hence, social sustainability dimension is approached from an angle of social acceptance.

6.3.4 Technological sustainability

The fourth dimension of sustainability is technology that is inherent in resource and environmental management. . No one can deny the fact that present day society is technologically paralysed and the market is being more and more customer driven where people are enjoying the "fast life" (Sharma, 2006). Modern society achieved its present day status not only because of technology but also due to the ability of technologists, who created it, to foresee the technology through the prism of technology, business and society. Those who could not merely remained in history.

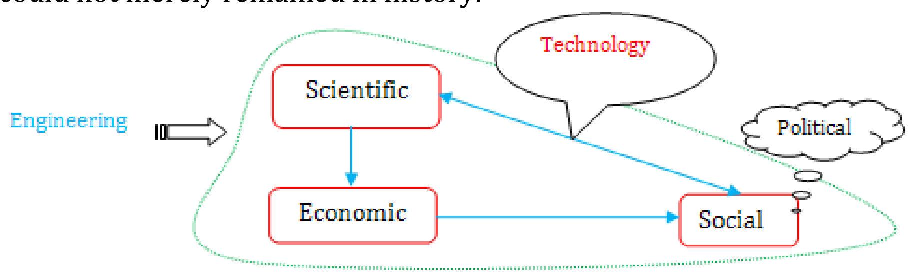

Figure 6-9: Dimensions of sustainability and resultant vector(Hasna, 2007a)

Figure 6-9 presents a hypothetical diagram of engineering relationships. Engineering is largely made up of an economic, scientific and social (political) discourse with technology being the resultant vector in that relationship, corresponding to the three-legged stool of sustainability. Although technology is often referred to as the science or study of the practical or industrial arts and applied sciences, the terms used in sciences are technical terminologies of methods and process, for handling a specific technical problem or finally, the system by which a society provides its members with those things needed or desired. The dynamics of sustainability are no different than for other human activities or interventions which impact the environment. Culture and technology evolve and adapt currently the insatiable lust of the rich for hedonism drives the creation of technologies as means self-gratification. In turn, these technologies have resulted in environmental stress on the ecology. The respective meanings of 'sustain' and 'able', in a nutshell, are 'keep going' and 'can'. This description of the emerging age of sustainability is not prescriptive. It is not a recipe for how to change a paradigm. It is simply a narrative of what has been happening in society for the last decade or so. However, it is essential to note that the age of engineering design is not "wrong," nor is the age of sustainability replacing the age of engineering design; rather, it is subsuming it.

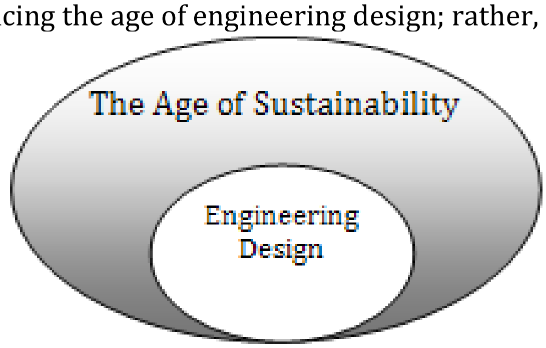

Figure 6-10: The age of sustainability encloses engineering design (Hasna, 2008c)

6.4 Conclusion on sustainability philosophy

This chapter had explored the scientific relationships between social, environmental, ecological, and technological parameters with respect to second law of thermodynamics that govern the transition to sustainability.

Thermodynamics is the science of energy conversion integrating thermodynamic principles in sustainability philosophy has a number of recognized advantages. However since thermodynamics is the science of energy efficiency, this science supports the concept of 100% recycling as unfeasibility. Ultimately this advocates that all engineering development and future technologies are bound by these limitations. This theory raises several questions about entropy reduction resource depletion and unavoidable negative environmental impacts of current practices. To which this mentioned thermodynamics philosophy confirms the physical limitations and is a sharp contrast to the optimist belief that problems (indefinite sustenance) might be resolved by future advances in technology and science. Finally how does this chapter contribute to the theme of this thesis, "A discussion on sustainability in engineering"?

Sustainability was reviewed from a celestial view of sustainability systems in respect to laws of thermodynamics, we have introduced the time dependency of sustainability with respect to entropy, and hence any suggestion that sustainability is indefinite is in disparity with our governing physical laws. Therefore, the ultimate objective of sustainability is the full integration of the natural, economic, and social systems, and this may be achieved through the integration of these objectives and not linear thinking and liner growth. It is also critical that we highlight that failing to consider entropy in a global context, is the issue with the current engineering practices.

Chapter 7. Sustainability Criteria Conceptualisation

7.1 Outline

In previous chapters, we reviewed the literature definitions and assessment methods, their development, role and limitations in promoting the basis of this discussion on sustainability in an engineering context. The objective of this chapter is to identify the significant sustainability criteria in the engineering context found in previous chapters; classify these criteria, conduct interviews with experts to assess "sustainability in engineering" decision-making processes, outlining the (economic, natural, social, technology and time indicators) criteria selection from the literature, in particular that mentioned in Chapter 2 and Chapter 3, and provide the rationale for adapting the risk management framework. This is divided into three phases as shown Figure 7-1.

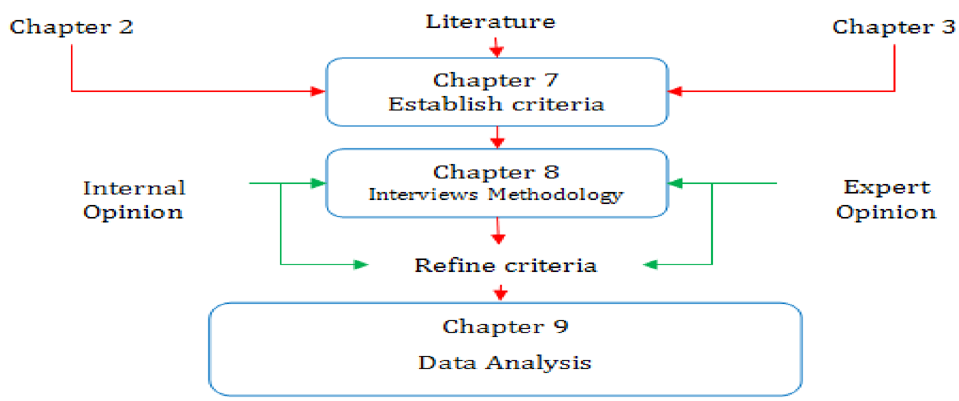

Figure 7-1: Chapter 7 overview

7.2 Research rationale

The aim of this study is to attempt to establish sustainability perceptions. In general, what are the links and relationships between these principles, concepts, criteria, factors, and the measurement of outcomes from engineering by extension technology? In particular, are there links between these concepts and specific criteria of metrics, so that these criteria can thus be theoretically founded on such concepts, as shown in Figure 7-2.

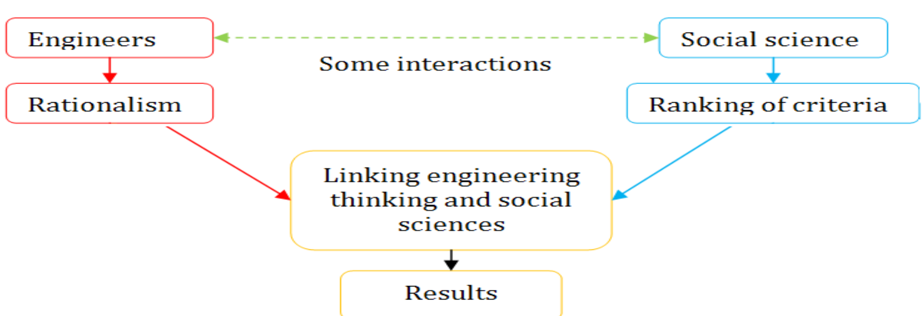

Figure 7-2: Conceptual framework convergence of two bodies of knowledge

7.3 Establishing criteria

The previous chapter had reviewed a number of assessment tools which may not be commonly recognized amongst engineers but the same time evidently entrenched in engineering. Conversely, the theme of this chapter is establishing sustainability criteria.

> "Sustainability indicators integrate environmental, social, and economic factors such that the complex cause-and-effect relationships between these multiple factors can be more readily investigated" (Guy and Charles, 1998) In addition, "an indicator is a representation of linkages whereby multiple effects can be monitored by a fundamental indicator" (Atkisson, 1995).

Hence, in regards to the intend design of indicators for sustainability in engineering, it is essential to come up with a merit-based indicator that provides immediate feedback on the design. therefore from a practicality perspective it is important that these design criteria issues be resolved early in the engineering design process (Conway and Barbier, 1988). Although it is recognized that no single process can describe a universal engineering approach. Lyytimaki and Rosenström,(2008) responded to the argument of building a sustainability indicator system without a tangible, framework may provide a

> "…cheap and quick solution that is sufficient for some situations. The drawback is that the organizing structure and relations between issues and indicators remain obscure and elusive. These kinds of ad hoc frameworks may also easily neglect important issues and highlight wrong issues…". "…The quantitative assessment of technical systems during the research and development, planning and structuring, and implementation and management phases of technological development is important for identifying and prioritising overall contributions to sustainability" (Assefa and Frostell, 2007).

The explicit incorporation of sustainability in the decision support process requires robust assessment of the social, economic and environmental consequences of potential options. This requires the use of sustainability criteria by which to assess these consequences in terms of whether the option is likely to move the system towards or away from sustainability objectives (Foxon et al., 2002)

> "Those with engineering expertise need to contribute at an early stage in the framing of problems, not just in problem solving; i.e. engineers should have a normative role as well as their more familiar analytical role. This concept of engineering adopting (or returning to) a normative role can be understood by examining the kinds of decisions in which professional engineers may be involved" (Clift, 2006)

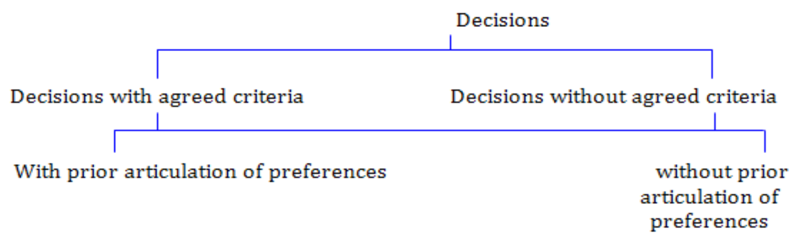

Figure 7-3: Classification of decisions (Cohon, 1978) cited in Clift, (2006)

Hence any attempts to construct a criterion to quantify sustainability in engineering must be accompanied by a strong decision making rational, Figure 7-3 shows a useful classification of decisions. Fischoff and Foster (1978; 1980) suggested 14 criteria that will affect the choice of strategies that decision makers will apply to a given design, listed in Table 7-1. Armed with these preliminaries and decision making theorems, let's now return to the questions of defining the principles, criteria and indicators.

Equity	Do those creating the hazard pay for mitigation? Or where inappropriate, is cost equitably distributed among all?
Timing	Will benefits be quickly realized?
Leverage	Will action lead to further risk reduction by others?
Cost	Is there a less expensive way of achieving the same results?
Efficiency	Can the policy be administered efficiently?
Continuity	Will the effects be continuous or short-term?
Compatibility	Is this strategy compatible with others that may be adopted?
Jurisdictional	What authority will have to enact this policy?
Economic	What is the economic impact of this strategy?
Environment	What is the environmental impact of this strategy?
New hazards	Will the strategy itself introduce new risks?
Potential	How much of the risk will the strategy reduce?
Reaction	Are there likely to be adverse political repercussions?
Freedom	Does the strategy deny basic rights?

Table 7-1: Design alternatives adapted from (Granot, 1998)

7.4 Principles , criteria and indicators

The development of sustainability indicators is needed in order to provide decision makers with information on sustainable development that is simpler and more readily understood than raw or even analysed data (Rotmans and de Vries, 1997). Chapter 40 (Agenda 21, 1992) called for the development of indicators for sustainable development at multiple levels. Furthermore indicators are important for the development of sustainability assessment in engineering since they offer the greatest contribution to achieving sustainability objectives. Agenda 21, acknowledged the significance of sustainability indicators (UNCED, 1992b). In particular, there is a need for highly aggregated and composite indicators, here defined as indices, in which condensed information is assembled. Comparable Sustainability indicators and indices with broad international acceptance are lacking (Malkina-Pykh, 2002). The literature is abundant with non-specific, aggregated and ideal indicator sets, proposed by various organisations with interests in sustainability, for example the report on company environmental reporting published by (European Common Indicators, 2003; UNEP, 1997; World Bank, 2002) the sustainable development progress metrics recommended for use in the process industries, as developed by the United Kingdom Institution of Chemical Engineers (IChemE., 2002) (see section 3.5.2); the sustainability indicators proposed by the Environmental Sustainability Index (ESI, 2005), Ecological footprint (EEA, 2005a, 2005b; GFN, 2005; WWF, 2005); World Business Council for Sustainable Development (WBCSD, 1997); and the United Kingdom Government Strategy indicators (UKG, 2007). These indicator sets have been identified as having a general focus on reporting towards sustainability. In addition more indicators were produced in the academic arena e.g. (Azapagic, 2004; Azapagic and Perdan, 2000; Becker, 2005; Boyle and Coates, 2005; Hes and Bates, 2003; Labuschagne and Brent, 2006; Sikdar, 2003b, 2007a).

In the literature on sustainability much attention is given to describing "how ideal sustainability criteria should be?" but little information is given on the detail. It was found that the literature lists the criteria to varying degrees by conventional normative criteria. In this chapter we will attempt to provide a working framework, and collate sustainability criteria SEETT, (social, economic, ecological, technological and time). Sustainability indicators are defined as the set of factors that may be used to assess a range of options.

> "Principles are normative definitions or goals for sustainability which aspire to a universal validity, which can be agreed upon by all. Criteria are the set of factors that may be used to make a judgement about the relative sustainability of a set of options. Indicators measure the past and current values of specific criteria, and may be used to set standards against which future performance can be assessed. Note that sustainability principles should remain constant over time, whereas the choice of criteria and indicators may change rapidly as knowledge advances"(Blackwood et al., 2004; Foxon et al., 2002)

Sustainability indicator systems encompass a variety of frameworks, dimensions, criteria, indicators, targets and visualisation strategies (Potts, 2006). The variety of processes and measurements can be analysed from a systems approach and classified by policy purpose and scale. A key component of the system is the interpretation of the term sustainability and how the concept is applied to the particular issue. Foxon et al, (2002) described a clear distinction between principles, criteria and indicators of sustainability as explained in Figure 7-4.

Figure 7-4: Relationship between sustainability principles criteria and indicators

The reviewed indicators suggested a number of common reoccurring themes, demonstrating a similar array of indicators used in literature. Note that due to different terminology, goals, scopes and end use, the indicators were streamlined into six distinct categories, social, economic, ecological, technological, and institutional. A lone category rarely discussed and recommended but needs to be implicitly covered was "time".

7.4.1 Sustainability indicators (SIs)

The science of sustainability indicators (SIs) emerged post the United Nations Conference on Environment and Development Agenda 21, Rio Summit (UNCED, 1992a). The definition of SIs is an important step, as the selection of sustainable solutions is based on these indicators (Balkema et al., 2002). SIs address the crucial issue of sustainability: How can it be measured (Bell and Morse, 1999).

> "Indicators are different from primary data or statistics in the sense that they provide meaning beyond the attributes directly associated with them and thus provide a bridge between detailed data and interpreted information" (Farsari and Prastacos, 2002; UNEP and WBCSD, 1998).

Indicators provide summary of information(Farsari and Prastacos, 2002)having significance beyond the value of the parameter (Hardi and Barg, 1997). Indicators typically provide key information about a physical, social or economic system (Gallopín, 1997; Veleva and Ellenbecker, 2001) provide a comprehensive analysis of various definitions, and demonstrate that an indicator has been defined as "variable", "parameter", "measure", "statistical measure", "a proxy for a measure", and "a subindex", among others.

> "at the more concrete level, indicators are considered variables. .A variable is "an operational representation of attribute (quality, characteristic, property) of a system". (Veleva and Ellenbecker, 2001)

Thus, indicators are variables In the case of engineering design variables; the same variables could have different corresponding values for different designs. In this section, the boundaries of sustainability indicators are defined.

7.4.2 Indicator-criteria limitations

Historical research on indicators has been descriptive in nature. This has been useful in the developmental phase of indicator application. Descriptive research in terms of criteria and indicators has been the frameworks proposed by (Bell and Morse, 1999; Bossel, 1999; Dahl, 1995, 2000; Hardi and Barg, 1997; Moldan, 1997). The main known limitations of using indicators;

1. Subjectivity."Sustainability is a subjective feature of any system , the subjectivity is inevitable" (Bell and Morse, 2008)
2. Availability of data, "which could further lead to measuring what is available rather than what is important" (Meadows, 1998);
3. Over aggregation, need to choose from system perspective. Consequently, most indicators have not generally been accepted for actual decision-making because of measurement, weighting and indicator selection problems (Bartelmus, 2001).

7.5 Principles of risk management

Traditionally, engineering design involves inherent design risks in the early stages of design that are not always carefully managed; one of main reason being the lack of tools and knowledge to simulate stochastic events (Amir, 2004). Engineering design is subject to multiple, competing tensions; four of the main tensions during system or product development have been identified by (Maier and Rechtin, 2000) and are shown inFigure 7-5According to Australian standard types of analysis; In a comprehensive review of risk management completed by (Pennock and Haimes, 2002), it is reported that there is a growing body of literature on project risk management composed of a myriad of different approaches and methodologies.

> "risk analysis may be undertaken to varying degrees of detail depending upon the risk, the purpose of the analysis, and the information, data and resources available. Analysis may be qualitative, semi-quantitative or quantitative or a combination of these, depending on the circumstances" (AS/NZS 4360:2004)

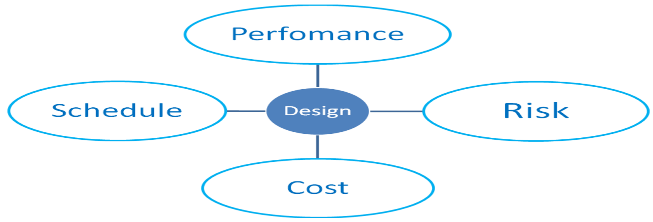

Figure 7-5: Architecting and design tensions (Maier and Rechtin, 2000)

In general, there is no one "right" technique to carry out project risk management (Haimes, 2009; Pennock and Haimes, 2002). A comprehensive approach to project risk management can be found in Chapman (1997), which suggested that project risk management should be a project in itself. To streamline the subsequent discussion on engineering projects risk and sustainability, this section defines and explains terms and concepts used in this chapter. According to Pennock and Haimes, Haimes(2009; 2002) there are two basic types of risk;

> Technical: "denotes risk in a project will fail to meet its performance criteria"
> Programmatic:"two major subcomponents: delay in schedule and cost overrun"

Armed with the above definitions of risk this is where we propose the idea to create a interlink between engineering project technical performance, cost and the project's complete sustainability, as shown in Figure 7-6. In all cases, risk is defined as the probability and severity of adverse effects as shown in equation (7.1) (Lowrance, 1976).

$$Risk = \sum_{i} N_i \times p_i \qquad (7.1)$$

where,

N_i = is the consequence (e.g., persons killed, injured) and
p_i= the probability of occurrence.

These two-dimensional components of risk capture are complex nature, but they also make risk a more difficult entity with which to work.

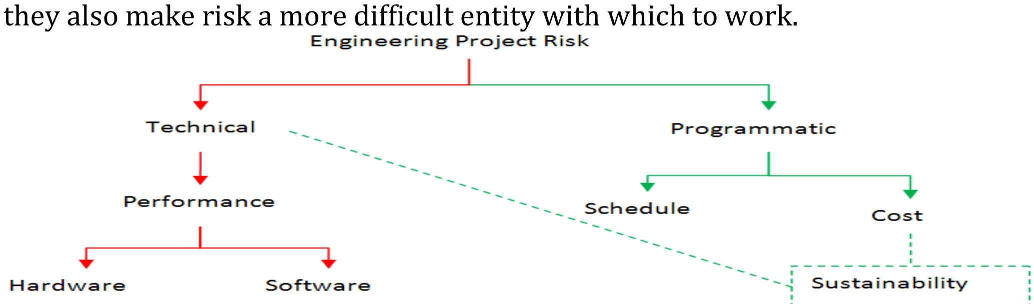

Figure 7-6: Engineering projects' risk relationships

7.5.1 Risk identification

Risky technological projects might affect the well-being of people.

> "Technological risks directly give rise to ethical issues. A question is asked, 'when is it justified to impose dangers on others and how should we judge whether a risk is morally acceptable or not?' Engineers define risk as a function of probabilities and unwanted consequences. Examples of unwanted consequences are a number of deaths or injuries, or a degree of pollution. Policy-makers use cost-benefit analysis to weigh the possible advantages of a technology against its possible disadvantages. Many social scientists who work in the field of risk analysis argue that cost-benefit analysis and the definition of risk as a function of probabilities and unwanted consequences are not sufficient to determine whether a risk is acceptable or not" (Roeser, 2006).

Many social scientists claim that since all risk judgments, also those of experts, include values, all risk judgments are subjective and socially construed. Objectivity equates with what is 'out there' and with what is quantitative (Slovic, 1999).

> "whereas all of the following notions are grouped under the label 'subjective': 'social construction', 'values', 'assumption-ladenness', 'judgment', 'intuitions', 'subjective assessment', 'qualitative', 'emotional', and 'contextual'. Some of these notions are by definition subjective or at least not objective, i.e. subjective assessment and social construction. However, the other notions are not necessarily subjective. Values, judgments, intuitions, qualitative, emotional and contextual are also not necessarily subjective notions. Judgment, intuition and emotion are 'subjective' in the sense that they are bound to persons who have them, but this holds for all our cognitive abilities" (Roeser, 2006).

The question is whether these abilities can help us assess what is really there. This is a philosophically controversial issue; it is far from philosophically obvious whether emotions, judgments and values are subjective projections or rather, if they are forms of objective discernment. According to most contemporary moral philosophers, moral values are not arbitrary or subjective.
Furthermore a number of methods exist to track and identify risks. For example While techniques such as Failure Modes and Effects Analysis (DoD, 1980), fault trees work well for assessment of pure system failure where each part can be examined individually to determine its failure modes. However, these techniques come with limitations for instance FMEA has limited effects for assessing sociotechnological systems failure which largely include assessment of engineering projects. Therefore raising the need for a broad-based, interactive, multifaceted approach to track the projects' sustainability risk, having said that we also identify the limitations of any analysis to capture all risk with a single model. In support of this theory we call on Hierarchical Holographic Modelling, which assumes

> "no real-life system can be adequately represented by a single model; to do so would be to present only one dimension of the system"(Haimes, 1981, 1998).

Hence, we propose investigating the critical and important facets that constitute sustainability system criteria. This is proposed through a comprehensive qualitative assessment to establish topics or a set of subtopics for engineers to refer to similar to sustainability assessment criteria.

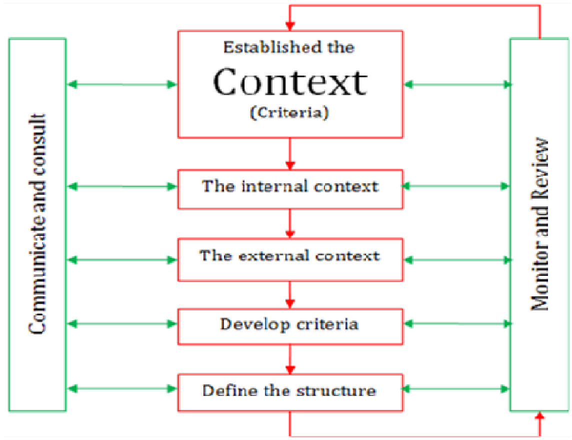

Figure 7-7: Portions of risk management process(AS/NZS 4360:, 2004)

7.6 Criteria conceptualisation

Whilst sustainability indicators act as a critical monitoring tool vital to the sustainable management of societal and natural resource and one of the most used tools for communicating information to decision makers,

> "Everything is an indicator of something but nothing is an indicator of everything"(Cairns et al., 1992).

Chapter 2 results indicate that there has been no conformity or consensus on a universal criterion for evaluating indicators from several points of view i.e.

> "reliability of supporting data, scientific rigor of definitions of indicators, validity of underlying assumptions and concepts, relevance of positive or negative trends for sustainability" (ASI, 2003).

If decision makers and engineers are to continue basing their decisions on the information thus provided, indicators need to be scientifically valid and policy relevant. In order to obtain scientific validity and ensure the complex interlinkages between social, environmental, economic, technological and time indicators, a scientifically-sound methodology is required on the data gathering, data processing and measurability. Since existing aggregated indicators are often criticised for their shortcomings in this respect.

> "This view suggests that a 'sustainability index' is impossible to design. They also suggest that indicators should be selected 'to maximize unique, relevant information and to minimize redundant information". (Young, 1997)

7.7 Criteria conclusion

The review of the literature undertaken in Chapters 2 and 3 helped to develop research questions aligned with sustainability criteria within the SEETT dimensions social, economic, ecological, technological and time relationships as listed in Figure 7-8:, essentially establishing a questionnaire context that is relative to the framework (AS/NZS 4360:, 2004). The process is also shown in

Figure 7-4. A framework is a conceptual model that can help in developing goals and indicators, Without a framework, indicators can easily proliferate and be little more than a conglomeration of disparate data (Becker, 2005). There are already numerous evaluation frameworks, as discussed in Chapter 3. However, these are industry specific and do not offer versatility for users to utilise a universal sequence. This review also highlighted relevant themes, concepts and theoretical frameworks that may be useful in pursuing these questions. Having fixed the list of criteria from a large body of literature by selecting the most recurring, a summary is listed in Table 7-2. The next step is to identify which indicators measure the system approaches sustainability/unsustainability. Ayres (1996)characterised three measures;

> "Measures of relative dependence of the economy on non-renewable sources of energy and materials, Measures of the *productivity* of energy and materials consumed by the economic system, and Measures of *dissipative loss*, especially of toxic and hazardous substances"(Ayres, 1996)

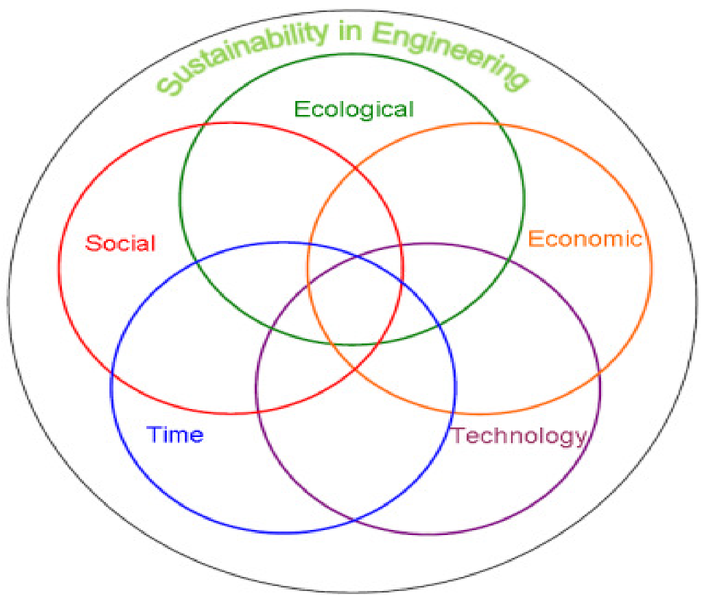

Figure 7-8: SEETT (social, economic, ecological, technological and time)

To set up a discussion on sustainability in engineering, the first step in this line of inquiry is to establish and define an indicator system that will form the basis of the interview process. "Many, in fact, are really indicators of unsustainability. Many debates and studies about the measurement of sustainability do not define, or even derive a common understanding, about what is to be measured"(Fricker, 1998, 2001; Fricker and Sculthorp, 1997)

Social Assessment Criterion	Ecological Assessment Criterion
Aesthetics appearance and nuisance Social cohesion dislocation and culture Relocation of people Knowledge or skill enhancement Education & training Recreational value Provisions for underprivileged Shelter impacts upon indigenous, or minority ethnic groups Heritage perseveration Improving of living standards Employment opportunity Occupational hazards (e.g. falls, fires, explosions, operation of machinery) Perceived risk loss of livelihoods Increased risk of natural hazards (e.g. floods, slips) Exposure to physically hazardous wastes (e.g. 'sharps') Nutritional value provided Increased food supply Mortality reduction-quality of life Impact upon cultural, historical or religious sites or values Accessibility increases competition, Ethnic Diversity Incorporation of women impacts upon women Impacts upon the poor Economic democracy Avoids illnesses Stress at work Spirituality, promotes justice, security Transparency participation Sanitation, communal violence Credit and investment Democracy transparency Quality of Life, equity, ethics Institutional, illness & disease Accident & injury, health & wellness	Virgin source of materials Recycled materials Origin of materials Greenhouse gas Manufacturing waste Packaging Existence of rate/ endangered species Disturbance of existing fauna Noise pollution Water Run off Monitoring environmental impact Smog creation Ozone Depletion Climate regulation Biodiversity reduction Design objective Non recyclable waste Energy efficient Use of fossil fuels for energy needs (i.e. CO 2 emissions) Energy consumption Acid rain precursors Global Warming Carbon monoxide (CO), nitrogen oxides (NO_X), sulphur dioxide (SO_2) Heavy metals (e.g. lead, mercury, chromium, zinc) Water quality Destruction of carbon sinks (e.g. forests) Release of other greenhouse gases Release of CFCs ploychlorinated dibenzo(p)dioxins (PCDD) polychlorinated dibenzofurans (PCDF) polynuclear aromatic hydrocarbons (PAH)polychlorinated bipenyls (PCB) hazardous chemicals dioxins1, furans2, PAH3, PCB4, nitroaromatics, hazardous chemicals pesticides, herbicides, asbestos
Economic Assessment Criterion	**Technology Assessment Criterion**
Costs Operation costs (raw material, labour, upgrades) Closure cost (i.e. site restoration, legal liability costs) Construction costs (i.e. land, equipment, infrastructure) Maintenance costs (new parts, down time, labour) Competition effects Stability Resource depletion Ecosystem productivity loss Employment GDP Deficit; and capital flow; debt Stability in prices; debt Social factor productivity Raw material Waste hazards Solid wastes or hazardous products Liquid wastes or hazardous products Gaseous wastes or hazardous products Capital, labour, fixed Viability CBA ,LCA , NPV Energy resources, fossil fuels Useful product lifetime Product disposition cost Clean technologies; adequate waste management Reduction of all forms of pollution Resource depletion, recycling revenue Consumption of goods and services Institutional Ethics	Source of the technology Indigenous to the area or Imported Relatively new/unproven System performance Decommissioning of technology Type of technology existing Processing/manufacturing Based on the use of natural resources Flexibility and adaptability business interruption Customer warranty cost Ecosystem productivity loss Loss of goodwill due to customer concerns Residual consequences Disruptive to the environment Resource depletion Ecosystem productivity loss Design iterations Resource scarce Renewable /non-renewable Hazardous materials used product & packaging mass Power use during operation Biodiversity reduction Needs and basic rights Leisure time and enjoyment of family life Social assistance and culture public safety Identity and self-esteem Health and social security Corruption, participation of civil society Cooperation , and agreement; solidarity and altruism Creativity governance expansion of civil liberties

Table 7-2: Sustainability criteria most recurring in literature

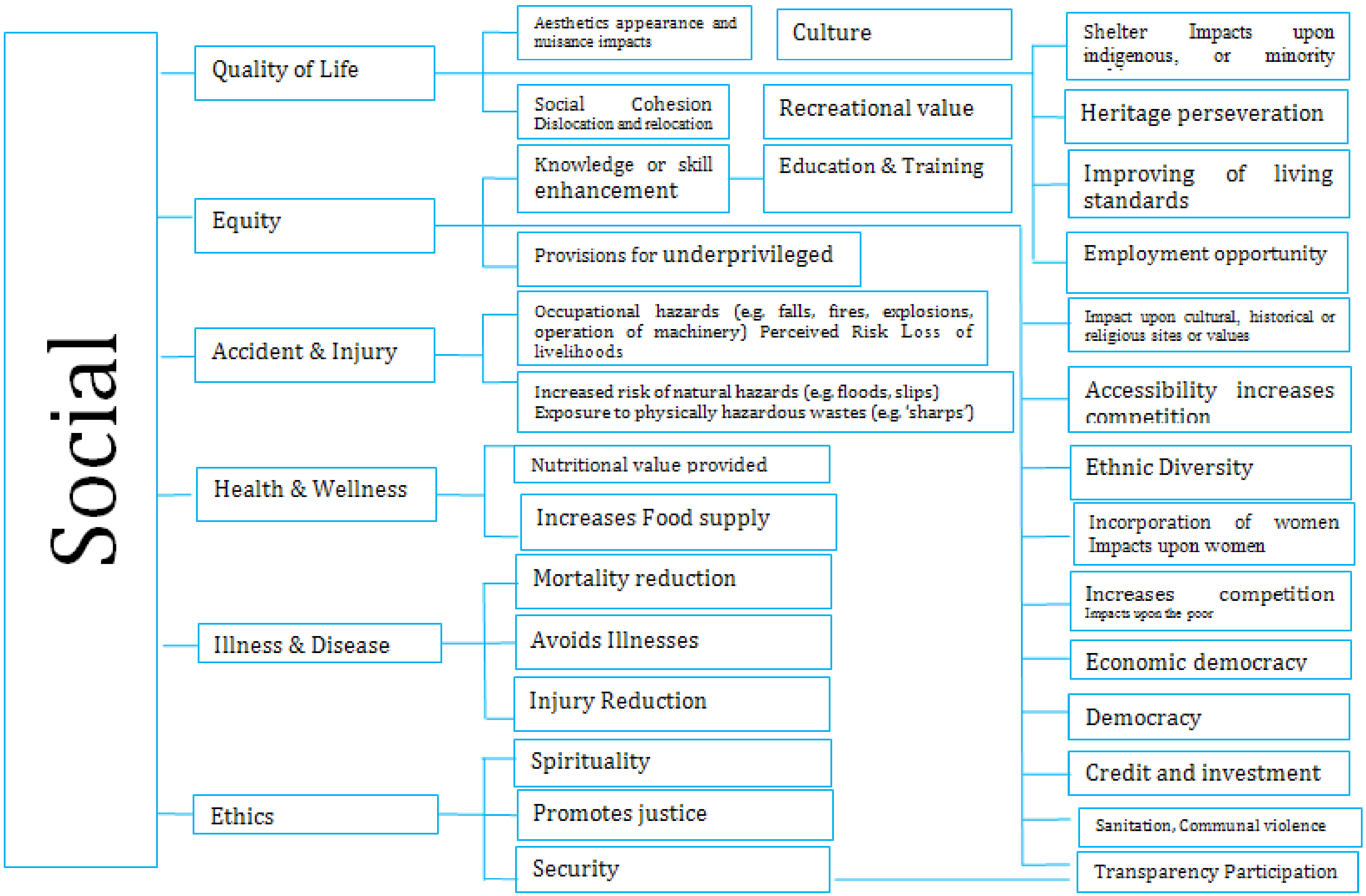

Table 7-3: Social Assessment Criterion

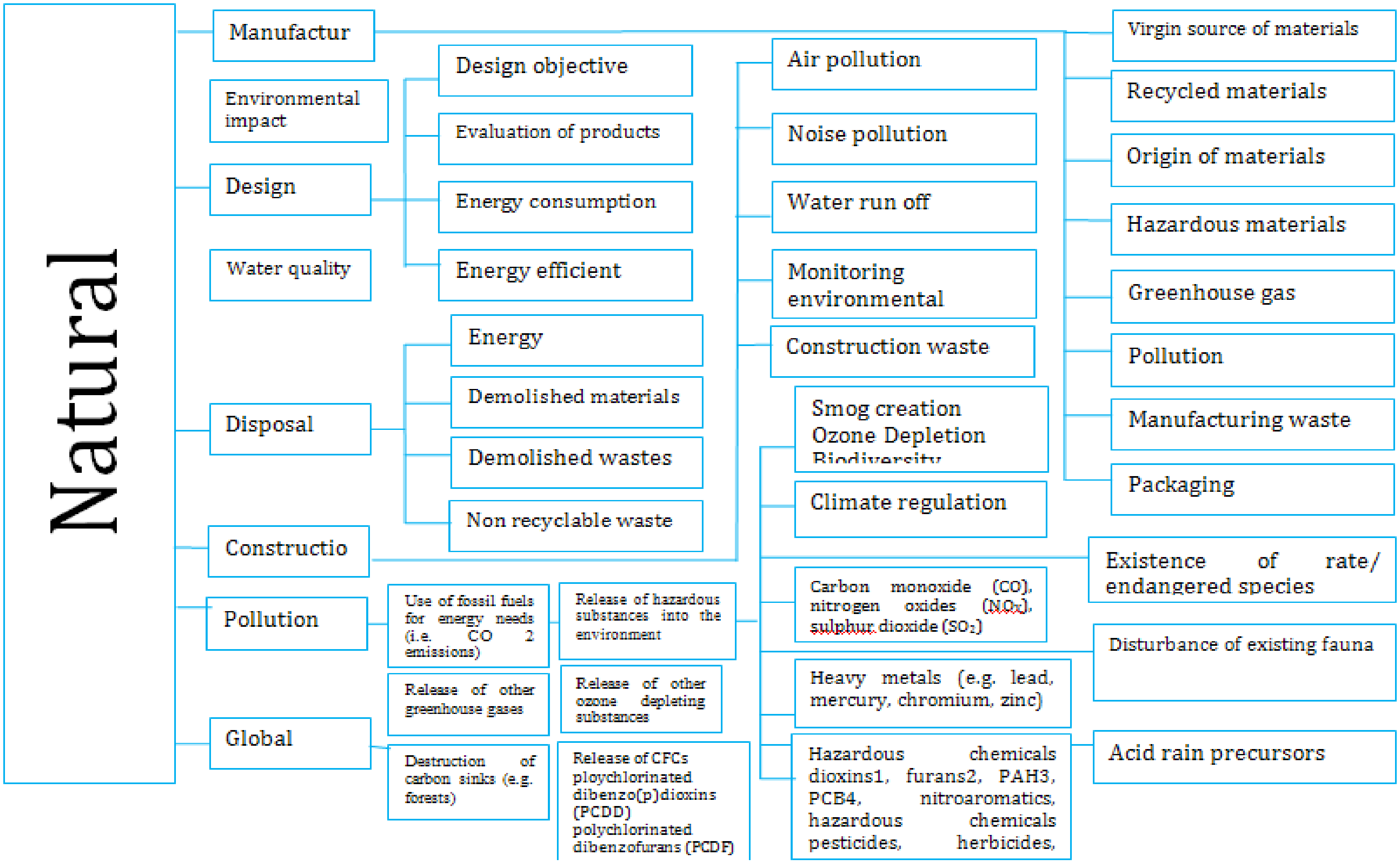

Table 7-4: Ecological Assessment Criterion

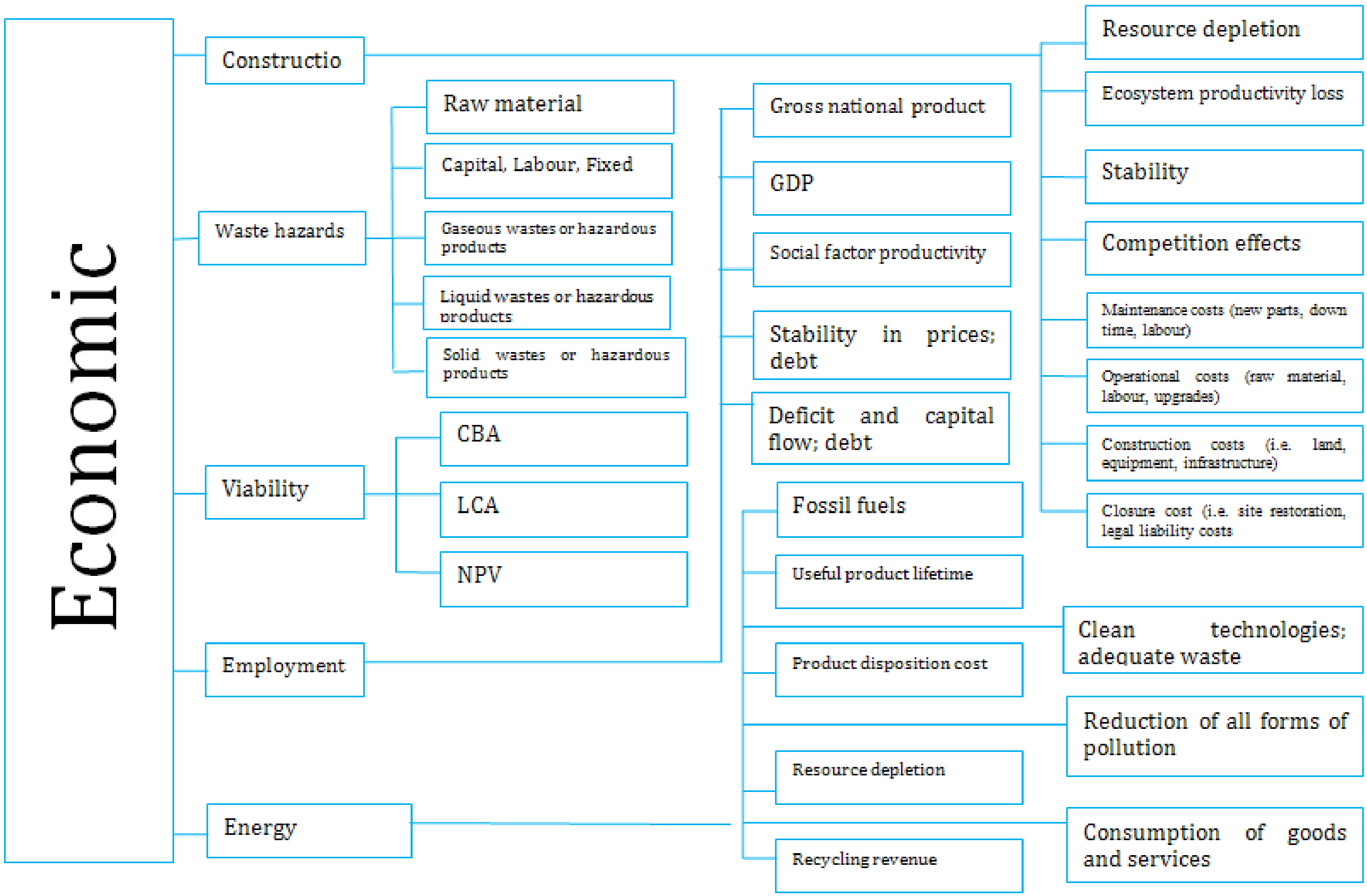

Table 7-5 Economic Assessment Criterion

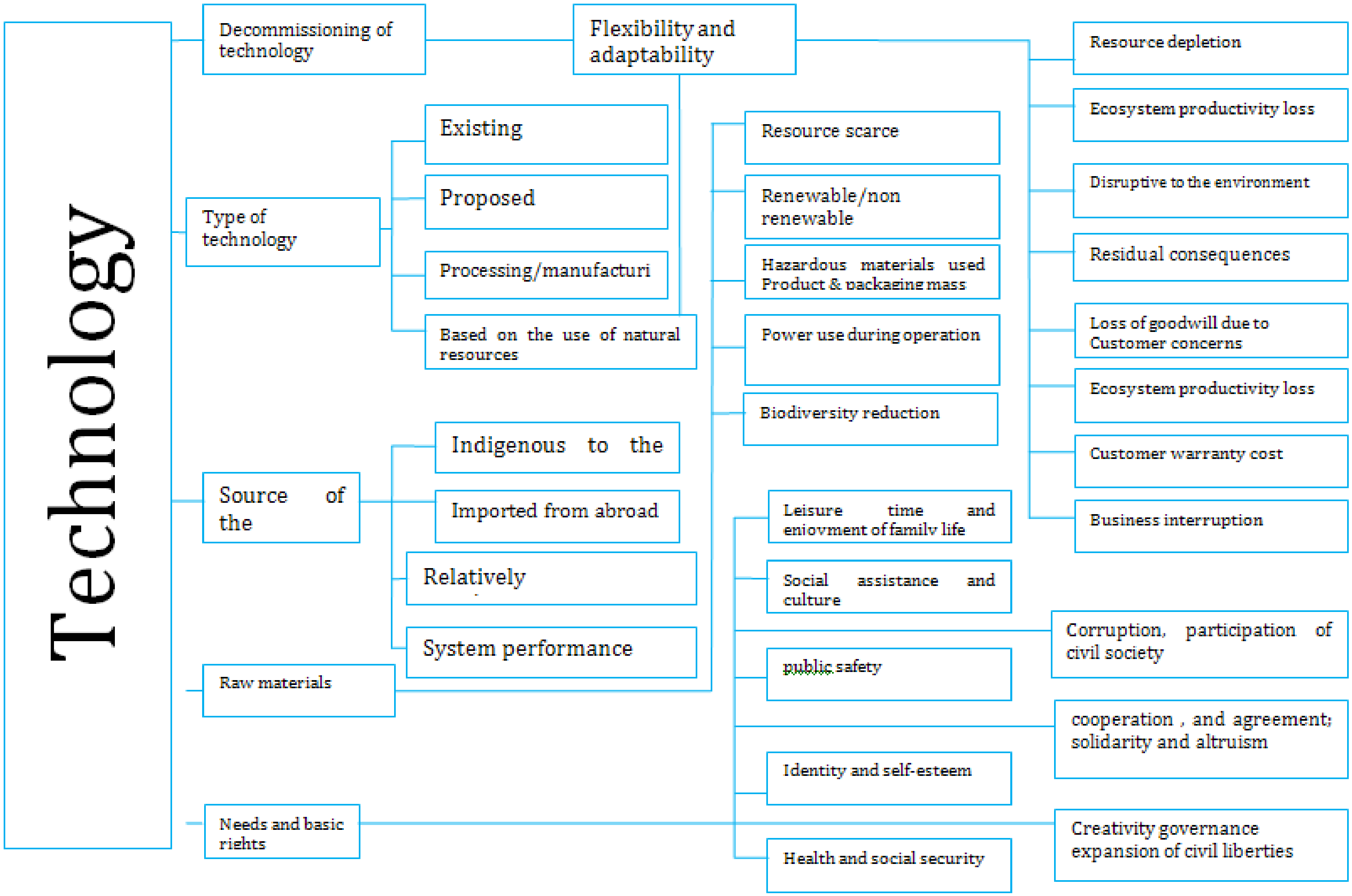

Table 7-6: Technology Assessment Criterion

Chapter 8. Research Methodology

8.1 Outline

The purpose of this chapter is to describe the research methodology used for collecting and analysing data used to test perception and importance of sustainability criteria, revised in the previous chapter. Initially, we present an overview of a qualitative research design to satisfy the research questions raised in Chapter 1 section 1.3.2. The study data was obtained via questionnaire; its main aim was to survey expert professional engineering opinion on the ranking of the criteria (sub criteria) of the four indicators identified in previous chapters, and to gauge the most important attributes in the assessment of sustainability in engineering projects. This chapter will present an overall research design that applies semi-structured interviews. The survey was conducted with currently practicing professional engineers using a structured questionnaire.

8.2 Research design

A review of the literature has resulted in the collection of criteria (Chapter 7) to guide examination of sustainability processes as they occur in engineering. However, the wealth of sustainability criteria available for engineers has the potential to cause confusion rather than support the attainment of the goal. For a subject already perceived as difficult, a lack of coherency can prove damaging. Having said that, many of the definitions material highlighted earlier demonstrate the wide reach of sustainability as a subject. Therefore, this chapter will progress the study from the research questions identified in section Chapter 1 section 1.3.2 to conclusions about those questions.

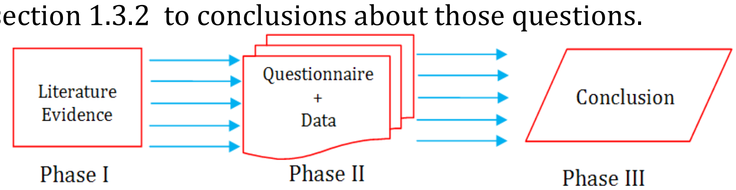

Figure 8-1: The research methodology phases

Initially, a summary of commonly used/ cited criteria from the literature was complied in phase I, literature evidence, to test the expert's usage/familiarity in terms of importance ranking using a Likert scale to rate the importance of these criteria for sustainability outcomes and decision making. In phase II, development of the questionnaire and data collection, we sought to evaluate the perceptions of currently practicing professional engineers on the importance (usefulness) of these criteria in sustainability measurement and outcomes in decision making by asking them to rank their importance.

8.3 Research intent

The overriding motivation behind this study is to explore and describe sustainability criteria and the extent of strategy implementation in engineering sustainability. This information is expected to be useful as the basis for future research and the development of sustainability policy and in industry and engineering education. This research aims to identify the commonly used/cited criteria from the literature resulting in the preparation of a questionnaire data-collection instrument to test the experts' usage, familiarly and understanding of the elements of the aforementioned criteria. In locating these elements, there is an opportunity to describe characteristics of sustainability. This is illustrated through the exploration as shown in Figure 8-2.

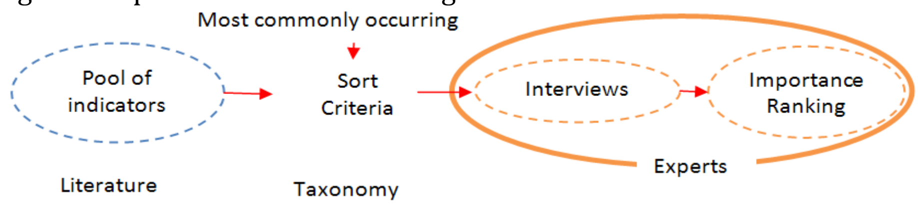

Figure 8-2: Exploration, description, explanation and prediction of sustainability criteria

8.3.1 Research questions

Despite engineering sustainability being at an embryonic stage, indicators/criteria are particularly important in developing a measurement systems. In order to determine the disjointed efforts to gain some coherence, the purpose of this study is to try to understand and explain the nature of the sustainability criteria relationships that exist amongst multi-disciplinary engineering professionals. Scale is important for defining the specific approach to measurement and outcomes in sustainability decision-making. According to (Moldan and Billharz, 1997; Potts, 2003), scale issues can be identified at the two levels;

1. Vertical: local, national, regional, international and
2. Horizontal: across sectors, government departments and institutions

Therefore a number of research questions directed this study:

(1) What is the perception of sustainability in engineering? What are its characteristics or attributes? Is it a utopian state or pseudo ideal process? Is it a strategy? Is it real or an illusion?

(2) Can sustainability as a process in engineering be measured? What are the key indicators and criteria? What are its characteristics and challenges? What tangible information and contextual factors affect decision makers when making sustainability decisions and how do these affect decision outcomes? How do we improve the design processes in engineering to include sustainability? Where do these complex issues leave engineers and designers? How would engineers apply sustainability to preliminary designs?

(3) Is it possible to identify and rank essential indicators deemed as important to the concept of sustainability in the engineering profession (projects or organisations)?

The interview method allows the researcher to answer "how" and "why" questions, that is, to understand the nature and complexity of the processes taking place. Questions such as, "how does an engineer rank sustainability criteria?" are critical ones for researchers to pursue.

8.3.2 Research methodology

The research methods selected in this study were qualitative in nature. According to Myers (1997, 2009)a research method is;

"a strategy of inquiry which moves from the underlying philosophical assumptions to research design and data collection"

Therefore, the primary purpose of this inquiry is to capture the meaning of sustainability phenomenon and relationships among known dimensions as they occur naturally in real-life contexts, where experimental controls are difficult to impose(Nastasia and Schensulc, 2005). In addition Myers (1997, 2009) defined

"all research (whether quantitative or qualitative) is based on some underlying assumptions about what constitutes 'valid' research and which research methods are appropriate"

I would emphasize the descriptions by (Denzin and Lincoln, 2000; Denzin and Lincoln, 2005) that procedural issues define how qualitative methodology is used to produce knowledge about the world. These research procedures are listed in Figure 8-3.

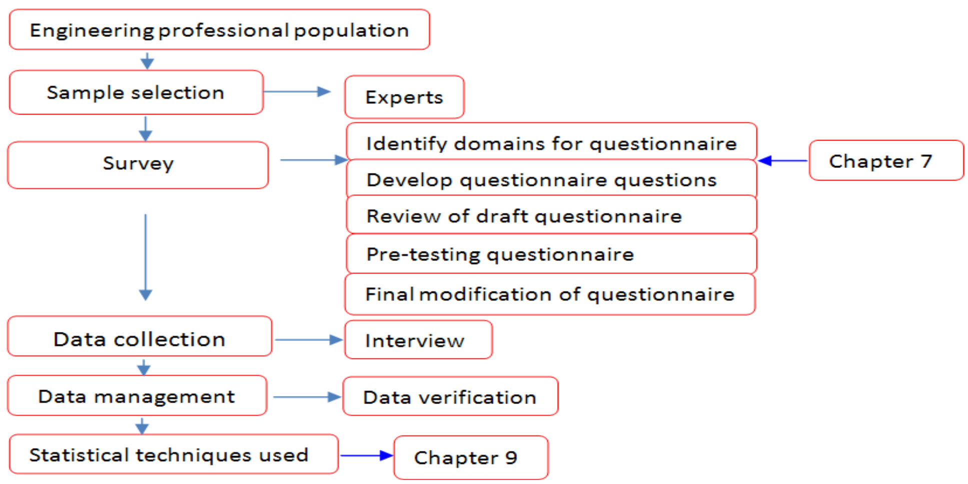

Figure 8-3: Sequence of research objectives

8.3.3 Sample selection

"Most products with which engineering industries are concerned will pass through many hands in the chain of resource extraction, transport, manufacture, distribution, sale, utilization, disposal, recycling, and final disposal"(IChemE, 2002)

Essentially the flow from suppliers, customers and contractors all contribute to the supply chain or lifecycle. Such is the varied nature of the engineering profession and industry, we felt that the sample frame should include decision makers from all links in the supply chain, including public and private sectors in engineering, so that the different groups' perceptions could be measured i.e. the individuals responsible within each of the discipline areas for example, design manufacturing, construction, maintenance, production, and the health safety environment. Furthermore, given that the questionnaire was seeking factor importance ratings on a one to five rating scale, to ensure statistically significant sample size we used the method proposed by Ballenger and McCune (1990) shown in equation (8.1) to calculate the sample size.

$$n = \frac{\left(Z_{\frac{\alpha}{2}}\right)^2 \times \sigma^2}{h^2} \qquad (8.1)$$

where

Z=reliability coefficient,
σ=estimated population standard deviation and
h=allowable tolerance level.

In this study, on a Likert scale from 1 to 5 rating scale a 95% confidence interval was selected: Z $\alpha_{/2}$ = 1.96, σ = = 0.66, h = ±0.2.The calculation for the required sample size, n, selected for the questionnaire was as follows:

$$n = \frac{(1.96)^2 \times 0.66^2}{0.2^2}$$

As a result, a minimum sample size of 43 would be required for each rating scale.

8.4 Qualitative research

Qualitative research has been variously defined, it is a way to portray, deduce and gain knowledge of about people to understand themselves and what is important to them about their situation (Tesch, 1990; Travers, 2001); it is deeply rooted different forms of human inquiry (Oliver, 2004). Qualitative research has been variously defined. According to Denzin and Lincoln (2000),

> "Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible'

> "In order to conduct and/or evaluate qualitative research, it is important to know what these (sometimes hidden) assumptions are" (Myers, 1997).

Myer suggested three categories as shown in Figure 8-4, based on the underlying research epistemology:

1. Positivist,
2. Interpretive and
3. Critical

> "Positivists generally assume that reality is objectively given and can be described by measurable properties which are independent of the observer (researcher) and his or her instruments" (Myers, 1997).

In the positivist version, it is contended that there is a reality out there to be studied, captured, and understood, whereas the postpositivists argue that reality can never be fully apprehended, only approximated (Guba, 1990). Epistemology is defined as the assumptions about knowledge and how they can be obtained. Ontology relates to basic assumptions about the nature of reality (Hirschheim, 1992).

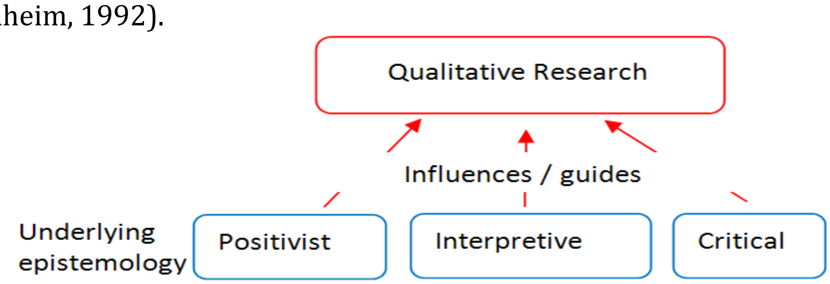

Figure 8-4: Underlying philosophical assumptions (Myer, 1997)

8.4.1 Limitations of qualitative studies

Qualitative data is often criticised for being "soft" or "intangible" (Neuman, 1997) According to Australian standard (AS/NZS 4360:, 2004) and Risk Management and Environmental risk management - Principles and process(HB 203:,2006)

> "Qualitative analysis uses words to describe the magnitude of potential consequences and the likelihood that those consequences will occur. These scales can be adapted or adjusted to suit the circumstances, and different descriptions may be used for different risks"

Qualitative analysis may be used to gather data on real events, recording what people say and do and studying written documents. This point of view is supported by the (HB 203:, 2006) point (c).

(a) as an initial screening activity to identify risks which require more detailed analysis;
(b) Where this kind of analysis is appropriate for decisions; or
(c) Where the numerical data or resources are inadequate for a quantitative analysis.

Assumptions	Reality is socially constructed Primacy of subject matter Variables are complex, interwoven and difficult to measure Emic (insider's point of view)
Purpose	Contextualization Interpretation Understanding actors' perspectives
Approach	Ends with hypotheses and grounded theory Uses emergence and portrayal. Places researcher as instrument. Is naturalistic Is Inductive Searches for patterns Seeks pluralism, complexity. Makes minor use of numerical indices Uses concepts are in the form of themes, motifs, generalisations and taxonomies Analyses by extracting themes or generalisations from evidence and organising data to present a coherent, consistent picture Uses particular research procedures so that replication is rare Is descriptive in write-up
Researcher role	Personal involvement and partiality Empathic understanding

Table 8-1: Adapted pre-dispositions of qualitative modes of inquiry

According to Ramos and Oliver (2004; 1989) the main known sources of limitations in qualitative studies are as follows:

1. researcher and participant relationship,
2. researcher's subjective interpretations of data, and
3. design itself

> "Embedded in qualitative research are the concepts of relationships and power between researchers and participants. The desire to participate in a research study depends upon a participant's willingness to share his or her experience" (Orb et al., 2001).

8.5 Experimental procedure

To understand the nature of any value system, first we must identify with the system's values and functionality. These clarifications require setting aside subjectivity for the values and evaluate their meanings in terms of goals and objectives. Coincidently management theory often wrestles with this overlap between values, goals, and resources and typically copes by arranging them into a hierarchy (Simon, 1976). Clearly there is a marked relationship difference between objectives and goals. If we utilize the organizational management analogy , where it is reported that organizations with visible, measurable objectives follow these objectives even when they diverge from goals(Clark, 1956; Thompson, 1967).Unless goals are represented by crystallized objectives, it's easy to reinterpret and misinterpret their goals (Selznick, 1984). To use the terms 'objective', and 'goal' 'in sustainability philosophy requires due care. To reinterpret sustainability methods goals and objectives creates ambiguity. Sustainability is often defined by its goals. However, this is subjective as goals/objectives are values. According to Selznick,(1984) it is possible for professionals to act with integrity and isolate themselves from competing interpretations of institutional values.. Hence, as a qualitative positivist researcher pursuing a critical analysis of the sustainability context in engineering, I am no less interested in ensuring that the outputs of this research are credible, useful and scientific. The experimental procedure consisted of extracting the expert's ranking of the sustainability criteria using a 5-point Likert scale as shown in Figure 8-5, and recording these results via the automatic questionnaire, as outlined in Appendix C.

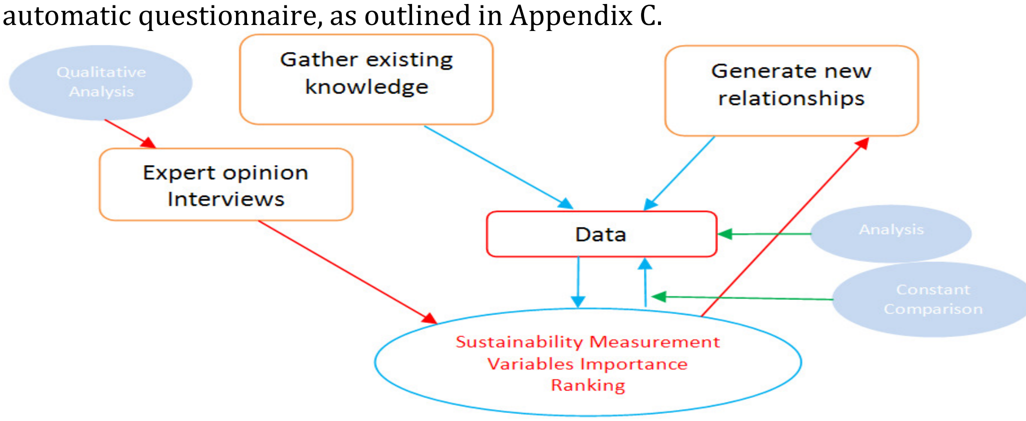

Figure 8-5: Global map of the experiments

8.5.1 Interview process

All interviewees received a formal written introduction at the start of the interview. Furthermore, the participants were offered a question and answer time post the introduction to ascertain full comprehension of the purpose of the investigation and its relationships. I briefly explained my academic and professional background and the aims of my research.

Hammersley (2002) explains the purpose of the interviews is to treat research as providing resources that practitioners can use to make sense both of the situations they face and of their own behaviour, rather than telling them what it is best to do. Structured interviews of 20 to 30 minutes duration were conducted; the interviewees were all currently employed in the engineering industry at various levels. The participants' employment positions came from three levels: (a) government, (b) academic / research and (c) private industry.

Murphy *et al* (2002)describes four methods of qualitative research: participant observation, interviews, written records and conversation analysis. Woods (1998) includes questionnaires as a method of qualitative research, writing that questionnaires are not among the most prominent methods in qualitative research, because they commonly require subjects to respond to a stimulus, and thus they are not acting naturally. However, they have their uses, especially as a means of collecting information from a wider sample than can be reached by personal interview. In this research, a combination of written records, conversation and questionnaire is used.

8.5.2 Recruitment of interviewees

Interviewees were selected on the basis of their professional backgrounds. I chose to interview practicing professional engineers for two main reasons: firstly, because they are at the forefront of industry and environmental governances through compliance hence, regularly implementing sustainability in engineering. Secondly, because the industry practicing engineer acts as an interface between environmental issues and public concerns that reflects reality. Therefore, due to the nature of my employment in the engineering industry over the past 15 years, I had, in turn, utilised my contacts to network and organise a number of design engineers as candidates to participate in the interviews, these candidates being considered leading professional design engineers. Basically, the respondents were selected from large engineering firms and consultancies, which meant that the respondents were mutually exclusive to one another. Initially, all interviewees were approached by way of an initial telephone contact where I introduced myself and followed up with a standard letter. The letter provided an outline of the research aims, the proposed timeframe and explained that participation would be both voluntary and confidential. All interviewees were identified only as engineers with a minimum professional requirement of either;

1. Currently working in engineering field ,
2. Preferred to be degree qualified persons.

I had also established a website dedicated to the assessment process where if a candidate was unable to meet with me, they could use the alternative method of filling in the questionnaire on the website. In total, there were 100 experts. this number of individuals was great enough to provide a diversity of experience informing responses and small enough to manage the collection and analysis of interview data.

8.5.3 The expert interviewee

In this section, I attempt to define the term ‘expert’ and outline what qualifies a person to be an ‘expert’. The person or team in setting the context of a problem defines a set of issues and selects a set of respondents who are experts on the issues. Burgman (2005) defines an expert as having the property of being-an-expert as taken to be self-evident. (Meyer and Booker, 1990) define an expert as someone who has the knowledge of the issue at an appropriate level of detail and who is capable of communicating their knowledge. Technical experience and training are sometimes called substantive expertise; whereas normative expertise is the ability to communicate, involving knowledge. Three attributes characterise an expert: effectiveness, efficiency and awareness of limitations. In

Australian federal courts, expert-opinion evidence is admissible (ALRC, 1985), but are expert judgments reliable? Burgman also reports that one of the main reasons expert judgments are used is in circumstances in which it is difficult or impossible to acquire data. There is evidence that experts do better than untrained people within their domain of expertise, as indicated in the much cited study by Fischhoff et al. (1982) of the reliability of expert's versus lay people's judgments.

8.6 Research Instrument and scale

Two schemes were applied in order to define the needs and capacities of decision makers using the reviewed definitions of sustainability and sustainability assessments, as described in Figure 8-6. This was assisted by key criteria to create the survey (the assessment questionnaire). The survey was answered by individualexpert ; a variable is a question presented in a statement.

Questions were gathered according to the different themes of the questionnaire. Each theme denotes one set of sustainability dimensions, SEETT the responses were coded using a Likert technique. Experts were asked to rate the items (criteria) by their level of importance, using a five-point scale; each degree of significance was given a numerical value from one to five, where 1= not relevant to the concept of sustainability in engineering, 2= low relevance to the concept of sustainability in engineering, 3= medium relevance to the concept of sustainability in engineering, 4= high, relevance to the concept of sustainability in engineering, and 5= critical relevance to the concept of sustainability in engineering. In doing so, the experts were not indicating what they believed; rather, they were judging how important each item was with respect to the construct of interest.

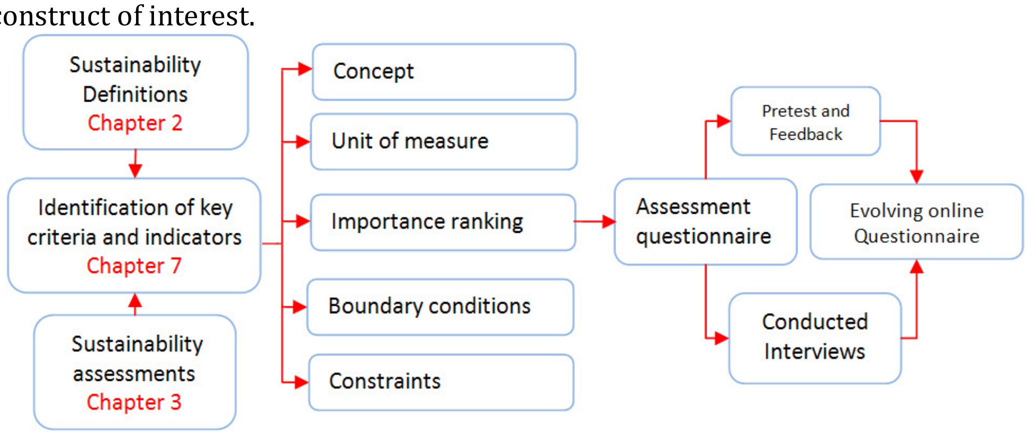

Figure 8-6: Questionnaire formation and strategy Research survey - questionnaire

The purpose of the questionnaire was to identify what issues were relevant to characterize, quantify criteria and indicators and to articulate sustainability in engineering as a concept. The questionnaire engages with the engineers to encompass a comprehensive contextual understanding of their own work towards achieving sustainability. Initially, I had prepared a draft framework based on the types of research topics to be covered in the interview. Those topics were:

1. Individual background including qualifications
2. The engineers'/experts' previous design experiences and sustainability consequences

3. The engineers'/experts' expectations and fears regarding the development of an assessment tool
4. Identification of simple, easy-to-use, clear guidelines or policies for everyday use
5. The engineers'/experts' practical concerns with assessment tools and their limitations
6. The institutional challenges related to the implementation of a universal sustainability measurement

The test interviews were helpful in identifying deficiencies of the initial questionnaire as it proved as too broad and lacking specificity. i.e. the questions did not help the interviewees consider the importance factor. Furthermore the suggested feedback helped identify more contextual questions, how do you identify sustainable practices in your workplace. That's why; the questionnaire structure was changed to include separate sections for each indicator, thereby containing the influence of the identified sustainability criterion. Furthermore, an open-ended question was included for each of the questions which encouraged interviewees to expand and explain their responses.

The new questionnaire was divided into four sections, designed to give interviewees a range of opportunities to describe their sustainability perception and how they rate the importance ranking of sustainability criteria.

The first part, questions 1-9 collected general information on the participants' demographics including age, gender, qualifications and experience including training history and educational experience in engineering to establish familiar ground. The questions about training and experience were intended to provide a context for interviewees to consider the influences on their perception of sustainability and to feel relaxed and speak freely about non-threatening matters.

The second part, questions 10-13 asked the respondents to identify their personal understanding of sustainability.

In the third section in which participants were asked to rate essential features of criteria deemed as important (indicators) to the concept of sustainability in the engineering profession (projects or organisations), a 5-point Likert scale was used for rating each factor. The categorical questions about the criteria enabled interviewees to describe their own role in industry and to articulate what issues were important when deciding on sustainability. The questions were descriptive, open-ended perception questions where explanations to those questions provided data that helped to illustrate the experts' views of sustainability and to identify the key 'micro themes' crucial to that view. The fourth and final section aimed to discover previously unnamed factors that they strongly felt were important in assessing sustainability in engineering; we also encouraged respondents to specify them. This evaluation does not claim to be a universal categorization, but shows a possible method of participation and resolving competing objectives. The new assessment questionnaire was then tested in an interview-based process with experts in the field, and where the experts provided feedback on the content. The interviews were digitally transcribed at the moment of the interview and the feedback was validated.

8.6.1 Measurement of variables

The variables used in the study were identified from the literature review as being those variables most needed in order to answer the research questions. Furthermore, the variables were embedded as individual questions in the questionnaire. The first group of questions elicited individual background information, including qualifications, as independent variables to obtain some idea of the perception of sustainability being surveyed; also, a number of descriptor variables were asked at the beginning of the questionnaire. Questions 1 to 5 were scaled as nominal variables. Social, economic, ecological and technological questions were the dependent or outcome variables of the study scaled on a 5-point Likert scale as ordinal variables; these questions represented the operationalisation of sustainability assessment and were fairly straightforward questions derived from the literature. No individual definitions or clarifications were provided.

8.6.2 Subjects and instrument bias

This qualitative research involves a natural interpretation of the experts' opinions and understanding of sustainability criteria in the engineering domain. This means that, as the researcher, I am studying the experts in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings. As stated by (Flyvbjerg, 2001), "the study of social phenomena is not, never has been, and probably never can be, scientific in the conventional meaning of the word 'science'"; furthermore "the open-ended nature of data collection and efforts to capture the emic perspective influence the roles of the researcher and participant in qualitative research" (Nastasia and Schensulc, 2005). In addition Klein and Myers (Klein and Myers, 1999) clearly defined the role of the researcher as follows;

1. Researchers themselves are the primary instruments of data collection.
2. Interpersonal skills of the researcher are critical to entering the natural settings, data collection, and negotiating meaning.
3. Researcher to declare and acknowledge their own biases, preconceptions, prejudices and assumptions.

This researcher has a technical background in chemical and process engineering. Prior to my commencement of this research, I believed that many engineering sustainability studies were disjointed and bolted on towards the end of the project and often were completed as a result of compliance pressure only. This established an a priori belief that sustainability assessments were related to poor knowledge and a lack of clarity on the role of engineers in sustainability.

8.6.3 Reliability and validity

According to (Golafshani, 2003), to ensure reliability in qualitative research, examination of trustworthiness is crucial.

> "while establishing good quality studies through reliability and validity in qualitative research, states that the "trustworthiness of a research report lies at the heart of issues conventionally discussed as validity and reliability" (Seale, 1999).

> "Major theoretical assertions of validity in qualitative research relate to two general approaches labelled transactional and transformational validity. Transactional validity is an interactive process between the researcher, the researched, and the collected data that is aimed at achieving a relatively higher level of accuracy and consensus by means of revisiting facts, feelings, experiences, values, beliefs collected and interpreted. Transformational validity is a progressive, emancipatory process leading toward social change that is to be achieved by the research endeavour itself" (Cho and Trent, 2006),.

(Onwuegbuzie and Leech, 2006) surmised three major threats to internal and external validity in the research process

- research design/data collection,
- data analysis, and
- data interpretation.

Triangulation is one form of validity. Bloor (1997) summarised an alternative version of triangulation in which

> "findings may be judged valid when different and contrasting methods of data collection yield identical results on the same research subjects"

A quantitative researcher attempts to fragment and delimit phenomena into measurable or common categories that can be applied to all of the subjects or wider and similar situations (Winter, 2000), and they also emphasize the measurement and analysis of causal relationships between variables (Denzin and Lincoln, 2000). Qualitative, interpretative research helps the researcher organize and describe subjective data in a systematic way (Glesne and Peshkin, 1992). Hence, I was bound by an ethical undertaking to collect the data accurately so it could be replicated over time, at different sites and populations, and with different researchers. As a critical researcher, I had recognised these limitations, I had "built-in the bounds of trustworthiness and credibility in a holistic approach to include all significant contributing factors, clearly listing the role of the researcher's 'self'. In the hope of comparing findings with other importance rankings

8.6.4 Ethical considerations of the interview process

Whilst Ethical issues in qualitative research are often more subtle than issues in survey or experimental research, care was taken throughout the study to ensure that appropriate ethical standards have been observed. According to (Peled et al., 2002) five interrelated assumptions guide our ethical thinking on research in general and qualitative social work research in particular:

(a) research ethics are an integral aspect of the research act and of each of the phases of the research process;

(b) ethical research empowers participants, particularly those of vulnerable and disenfranchised;

(c) ethical research benefits participants;

(d) ethical research prevents harm for participants and involved others; and

(e) ethical research requires researchers' technical competence.

The nature of qualitative research and the role of the researcher as an instrument necessitates particular attention to ensuring the trustworthiness (veracity or validity) of findings (Nastasia and Schensulc, 2005). There are different stances regarding ethical issues in qualitative research. These include the absolutist stance, relativist stance, contextualise stance and deception model (Guba and Lincoln, 1994). According to (Makgoba, 2003) field research is an approach based on human interaction, rather than one viewed as outside human interactions. Field investigators themselves are the measuring instruments (Lipson, 1994). Guillemin and Gillam (2004) delineates two dimensions of ethics: the first is procedural ethics, the kind mandated by the Institutional Review Board (IRB) committees to ensure procedures adequately deal with informed consent, confidentiality, and rights to privacy, deception, and protecting human subjects from harm. The second is ethics in practice, or situational ethics, the kind that deals with the unpredictable, often subtle, yet ethically-important moments that come up in the field.

> "There is an attraction between utilitarian ethics and scientific thought as it fits the canons of rational calculations. No control groups were used, it was carefully explained to the participants that participation was optional and that it was their decision as to whether they did so or not. The interviews were conducted with no coercion or pressure in accordance with Christians' (2005) four main themes: (a) informed consent consistent with its commitment to individual autonomy; (b) deception-informed consent opposes deception; (c) privacy and confidentiality must be assured as the primary safeguard against unwanted exposure; and (d) accurate data that are externally and internally valid are the coin of the realm, experimentally and morally."

During the conduct of the research experiments, every effort was made to ensure: informed consent, privacy, confidentiality of all information obtained from participants and an accurate translation of data, as my primary concern was that the confidentiality of all participants was respected and that my investigation should cause no harm. To concur with the points of view of (Christians, 2005) and (Peled et al., 2002), the following steps were undertaken with all involved participants in the research; the research topic, scope and purposes were discussed with participants; to ensure confidentiality, no private data that could identify a participant was used; to ensure anonymity, the names of the participants were not recorded; and participants were provided with an information sheet that asked for verbal rather than signed consent. Those interviewed were made aware that no audio or video recordings were made. Finally, the research topic and questionnaire were reviewed by the Ethical Clearance Committee at the University of Southern Queensland and ethics approval was granted (reference number H07STU713).

8.7 Conclusion

This chapter has considered the research methodology, including data collection and ethical considerations. The interview method will help to streamline key sustainability assessment terms. The next chapter sees the implementation of this methodology data analysis to answer the research questions.

Chapter 9.
Data Analysis

9.1 Summary

The methodology to gather data for this survey has been described in the previous chapter. This chapter sets out the analysis of interviews conducted as the previous chapter to investigate the importance ranking held by experts (engineering decision makers) in regard to the concept of sustainability in engineering. To provide a balanced view of sustainability in engineering, there must be key indicators in each of the five areas (social, economic, environmental, technological and time). This was tested by four questionnaire topics areas. This chapter provides an analysis of the statistical data and consists of four sections, covering the analysis of the collected data, commencing with the descriptive sociodemographic analysis of respondents in section 9.3. Next, the quality of the measurement used in this study is examined using factor analysis in section 9.5. Finally, conclusions are drawn in section 9.8 for interpretation and usage.

9.2 Analysis of qualitative data

Interviews were conducted throughout the duration of this research project with experts on a random, convenience basis in order to clarify possible problems between interviewees. The random nature of the selections provided confidence that the sample interviewed would be impartial. The data collected from the questionnaire was organised around (Appendix C)

Questionnaire topic 1

> Demographics including age, gender, qualifications and educational experience.

Questionnaire topic 2

> Personal understanding of sustainability; what is the engineers' awareness of sustainability definitions and assessments? what are the engineers' perceptions of sustainability?

Questionnaire topic 3

Importance ranking of 32 indicators

Questionnaire topic 4

> Descriptive open-ended perception questions to discover previously unnamed factors; what is the engineering perspective on applied sustainability, criteria and sub-criteria?

9.2.1 Data preparations

Prior to conducting any data analysis, the normality of the data was considered because non-normality will affect both the choice of estimation methods and the proposed factor analysis. The data was examined to understand the relationships between factors and variables. The data preparation strategy included basic editing, cleaning and screening of data entry, checking missing data and the outlier's verification. Initially, the categorical responses were coded in ordinal categories 1-5 and inputted into SPSS. Lower numbers are assigned a lower importance. The Internal Reliability and Item-Total Correlation Analysis was conducted using SPSS. The Factor Analysis was conducted using SAS and the 1-ANOVAs and Interval Graphs were conducted using Minitab. The data distribution shown in Figure 9-1 provides a visual display of the distribution of responses by factor. Some factors are more normally distributed (e.g. v16) while others are more positively skewed (e.g. v3, v29). While normality is an important assumption for many statistical tests, the constraints of having only 5 response choices will distort the distribution of data, making it difficult to fully understand the actual degree of non-normality. While having normally distributed data is ideal, for the test conducted in this chapter, it is not a fatal flaw.

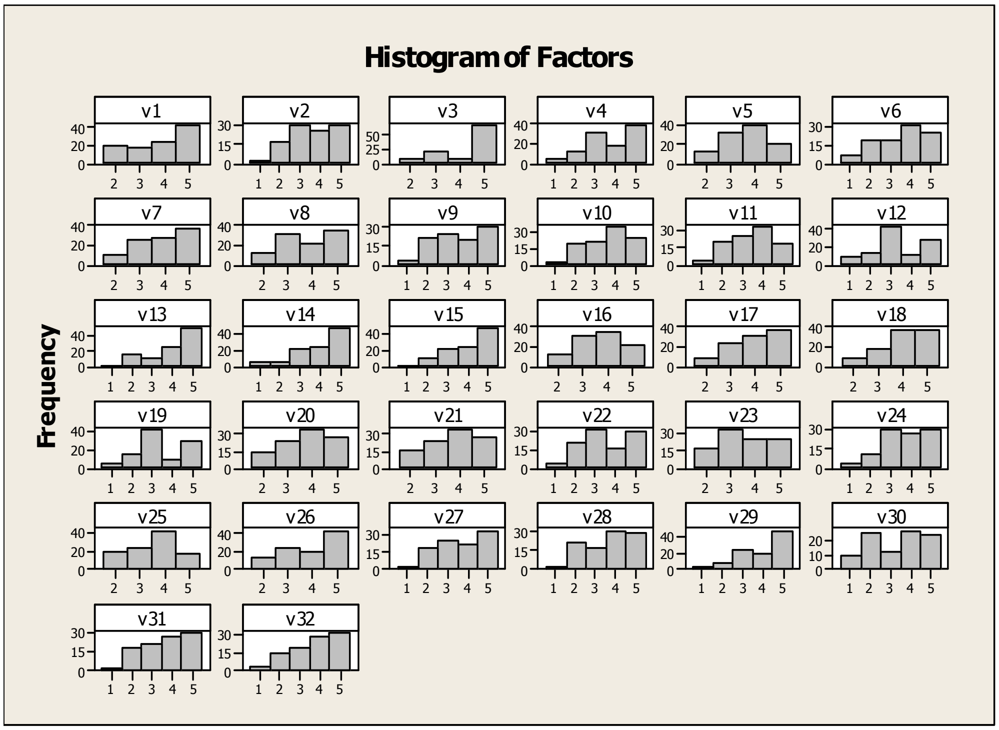

Figure 9-1: Distribution of responses

9.3 Socio-demographic profile of respondents

The first part of the questionnaire was used to collect data on issues related to demography: age, gender, marital status, cultural background, educational levels, experience, and sector of employment. Frequencies, means, and standard deviations (SD) of variables were used to describe the demographic characteristics of the sample. The data was combined into groups or classes of "years of experience" as a way to generalize the details of a data set while at the same time illustrating the data's overall pattern. The x-axis represents the data values arranged into "years of experience" classes while the y-axis shows the number of occurrences in each class. The median years of experience of the respondents is 13 (min 1 and max 33).

Figure 9-2: Distribution of participants' years of experience as an engineer

In Figure 9-2, the data are clustered on the lower or left-hand side, which is known as positive skew. Hence, the median was used instead of the mean due to the positively-skewed distribution of "years of experience" which can be seen in the graphical summary in Figure 9-2. In addition, the respondents' age had some influence on their understanding of the engineering industry. Figure 9-3 shows that the data set is normal and is without skew due to the absence of outliers concentrated on one particular side of the distribution. The respondents' average age was 40 (min 18 and max 39); the distribution is shown in Figure 9-3.

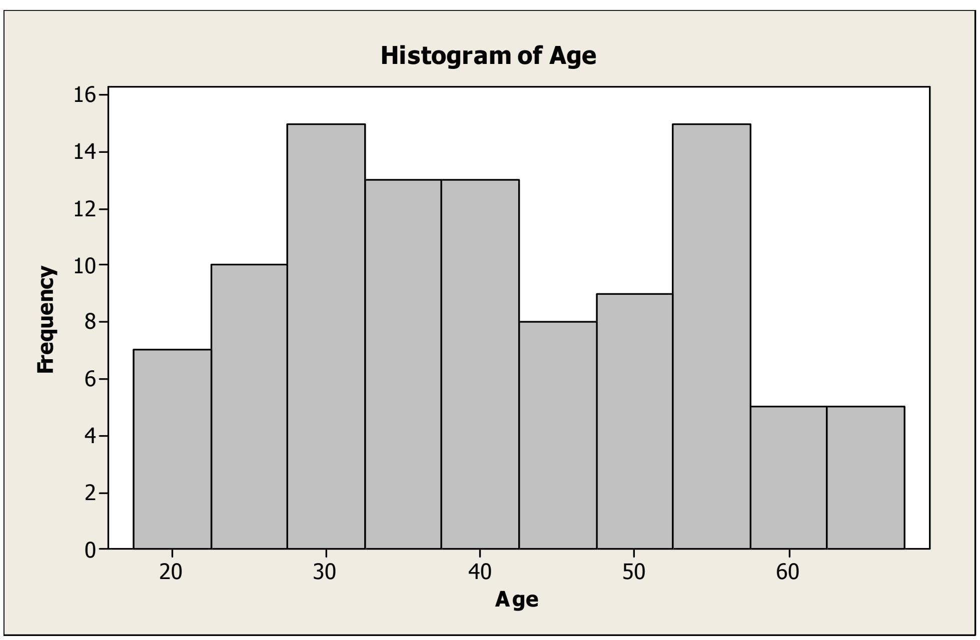

Figure 9-3: Distribution of participants' age in years

	Frequency	Percent
Gender		
Male	84	85
Female	15	15
Marital Status		
Single	33	33
Married	54	54
Neither	13	13
Level of Qualification		
PhD	13	13
ME	16	16
BE	16	16
MS	8	8
BS	11	11
MA	5	5
Trade	14	14
TAFE (Technical and Further Education)	6	6
High school	10	10
Consider self as 'expert'		
Yes	93	93
No	2	2
Missing	5	5
Industry		
Manufacturing	10	10
HSE	11	11
Design	22	22
Construction	22	22
Maintenance	23	23
Production	11	11
Missing	1	1
Area of Employment		
Administration	23	23
Management	26	26
Technical	45	45
Other	6	6
Specialization		
Environmental	30	30
Chemical	18	18
Electrical	20	20
Mechanical	12	12
Process	8	8
Civil	12	12

Table 9-1: Frequencies and percents of demographic variables

(Percents and frequencies are equal since there were 100 respondents)

9.3.1 Industry

There were no significant differences between the top score and the different industry groups to which the respondents reported to belong. These groups are shown on the y axis of Figure 9-4. In fact, the only factor in which there is any significant difference is for factor 32: "Engineer's involvement in decision making". A graph of the means is shown in Figure 9-4 with a 95% Bonferonni CI, the mean correction. In Figure 9-4, the non-overlapping confidence intervals indicate that the importance ratings between "construction" and "production" and "construction" and "design" have differing participation in sustainability decision making in the respective industry organisations. Engineers' involvement appears to be more important for the construction industry and less important for design and production, as it relates to sustainability in the engineering importance ranking. The mean 'construction' response is 4.36

(n=22), whereas the mean 'production' response is 3.09 or construction industry respondents report engineers' involvement being about 41% more important that the production industry and 32% more important than design (which has a mean of 3.318 from 22 respondents).

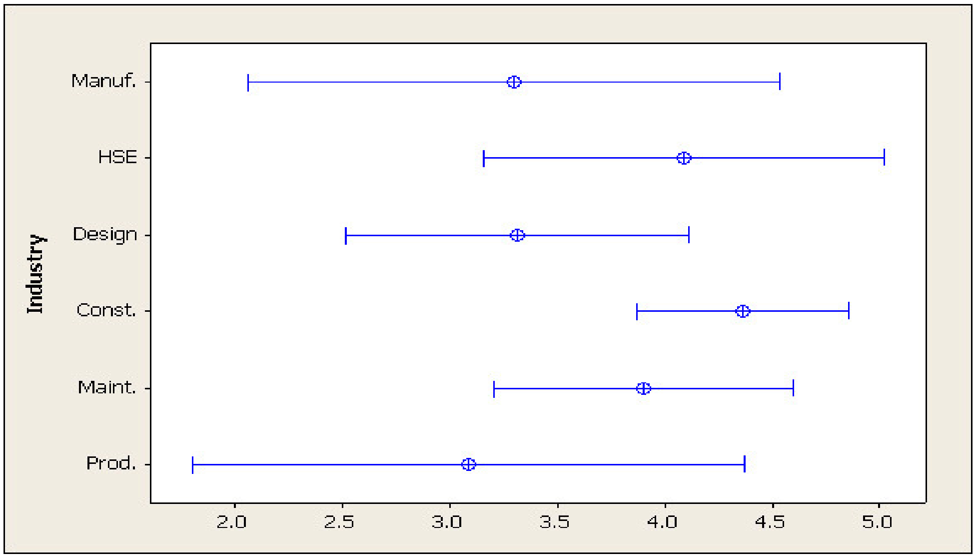

Figure 9-4: Importance of ranking versus the type of industry for factoring engineers' involvement in decision making

9.3.2 Area of specialization

There were no significant differences in the top score between any particular areas of specialization. The only factor which showed any discrimination was on factor 4, employment.

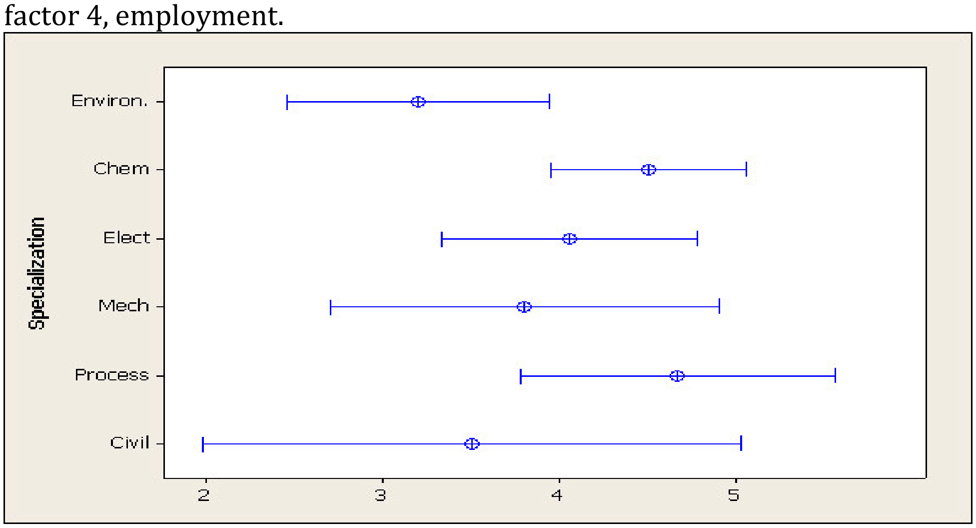

Figure 9-5: Importance ranking of factor "promotion of opportunities for employment" versus area of specialization

The only difference appears to be the environmental specialization which has a lower importance rating on the employment factor, compared to chemical and process. When assessing the importance of the factor "promotion of opportunities for employment" in respect to the concept of sustainability in engineering, it was found that employment was about 45% less important for environmental (3.2, n=25) than for chemical (mean = 4.5 n = 18) and process (mean =4.66, n=6). This was illustrated through one-way analysis of variance (ANOVA analysis) conducted using Minitab; the output of this analysis is shown in Table 9-2.

```
Source  DF      SS    MS     F      P
Speci    5   24.22  4.84  3.91  0.003
Error   83  102.88  1.24
Total   88  127.10

S = 1.113   R-Sq = 19.05%   R-Sq(adj) = 14.18%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level   N   Mean  StDev  ------+---------+---------+---------+---
1      25  3.200  1.291  (-----*-----)
2      18  4.500  0.786                 (-----*------)
3      20  4.050  1.099           (------*-----)
4      10  3.800  1.033      (-------*--------)
5       6  4.667  0.516              (-----------*-----------)
6      10  3.500  1.434   (---------*--------)
                         ------+---------+---------+---------+---
                            3.20      4.00      4.80      5.60
```

Table 9-2: One-way ANOVA output for specialization versus the factor for employment

9.3.3 Educational differences

Education attainment was dichotomized into those who had college or higher education (n=84) and those who had trade school, high school or TAFE (Technical and Further Education) qualifications (n=16). There were several factors which showed different importance rankings towards sustainability in engineering. For example, for factor 12, 'Stress at work', there is a significant difference between the rankings of those without college or higher education and those with, the former group ranking stress at work as much more important in sustainability in engineering (p<.01). The difference is strong, with a mean of 3.3 vs. 5.0, or 51% higher average importance. In fact, of the 60 responses, all 10 in the lower education level provided the highest response of 5, indicating that stress at work is overwhelmingly critical to this group.

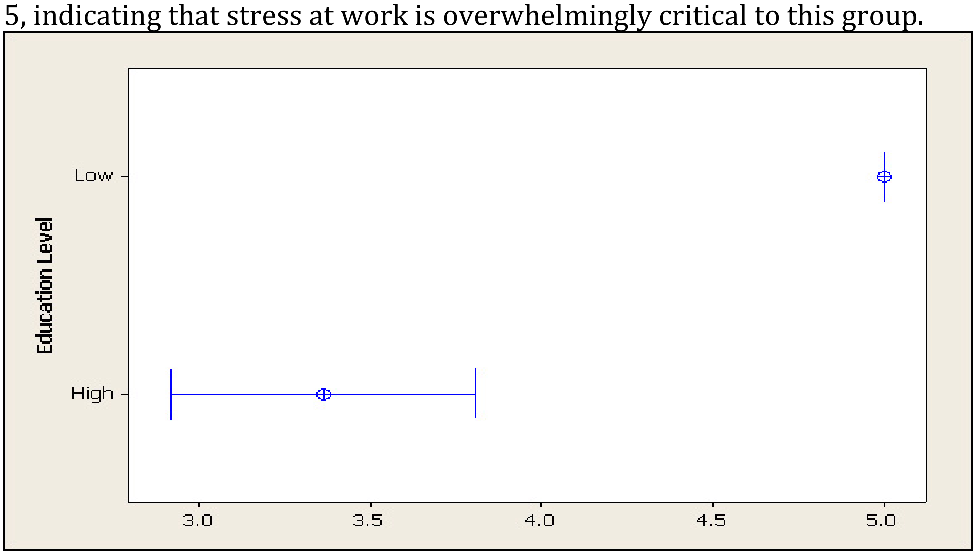

Figure 9-6: Importance ranking for factor 12, 'Stress at work' versus educational level

While the factor '*Stress at work*' had the largest effect size (difference between groups), other factors showed differences greater than expected from chance fluctuations alone. They are:

1) respondents with a higher educational attainment have a mean importance rating for 'Pollution control' which is 17% higher than those with a lower educational attainment (3.82 versus 3.14 $p < .10$)
2) respondents with a higher educational attainment have a mean importance rating for 'Performance of the system' which is 19% higher than those with a lower educational attainment (3.1 versus 3.7 $p < .05$)
3) respondents with a higher educational attainment have a mean importance rating for 'Intergenerational Equity' which is 15% higher than those with a lower educational achievement (4.2 versus 3.6 $p < .05$).

9.4 Participants' perception of sustainability

In this section, we analyse the data from the third part of the questionnaire, the participants' perceptions and understanding of sustainability. For responses to question number 10, as shown in Figure 9-7, 78% rated familiarity with the Brundtland report and its definition of sustainability as medium or higher and 45% rated it as high. Only one respondent rated it as not relevant; and no respondents rated it as critical.

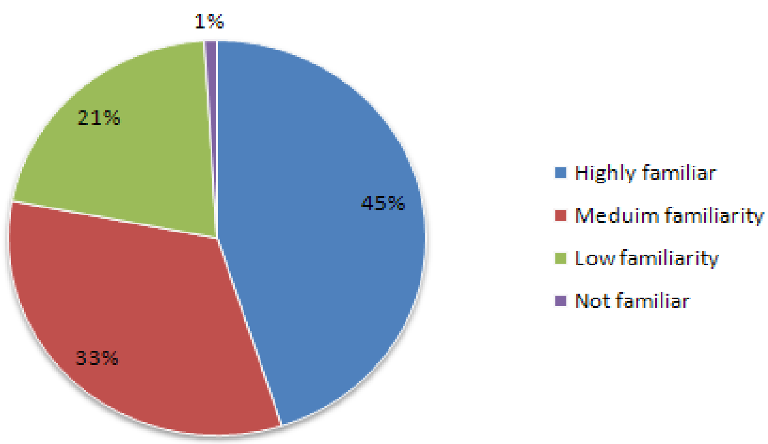

Figure 9-7: Participants' response to 'Familiarity with the Burdtland report and its definition of sustainability'

Responses to question 11, as depicted in Figure 9-8, show that 39% of participants rated the implementation of sustainability in the participants' respective engineering organization as low or not relevant and 38% rated it as high or critical.

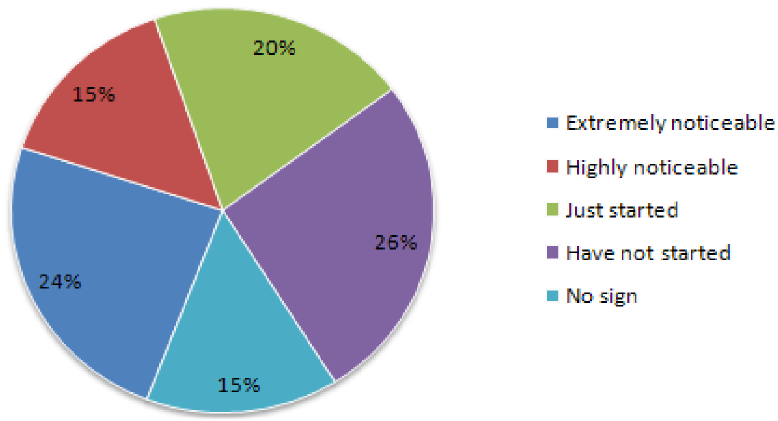

Figure 9-8: Participants' responses to "Rate the implementation of sustainability in participant's organization

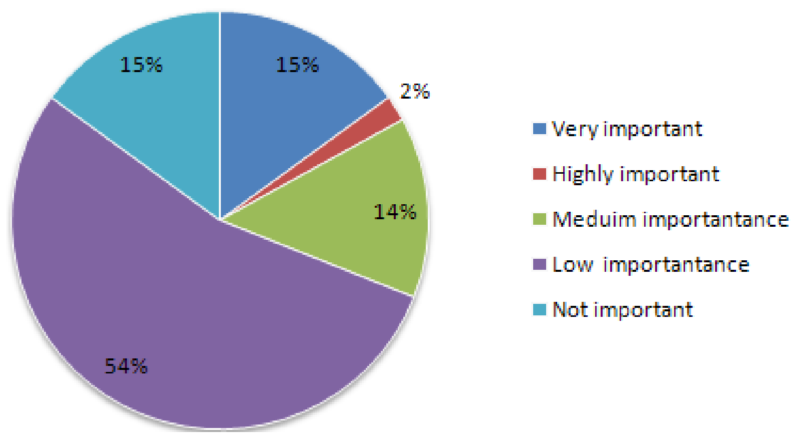

Figure 9-9: Participants' responses to "What is the importance of the sustainability policy in participant's organization?"

Responses to question 12, as shown in Figure 9-9, suggest that the sustainability policy in the participant's organization is not an important issue, as 69% of respondents rated it as either low or not relevant.

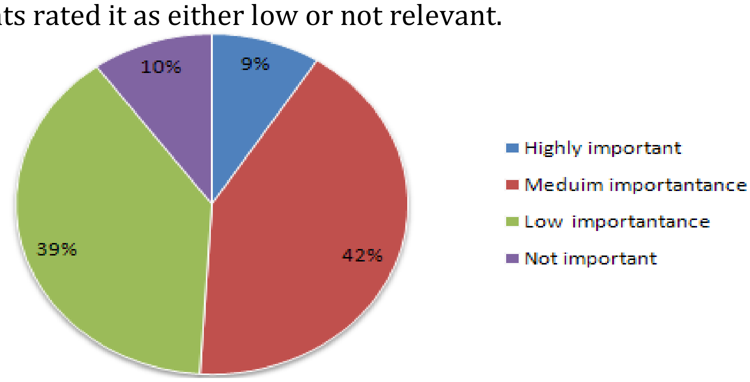

Figure 9-10: Participants' responses to "What is the importance of sustainability to you personally?"

In responses to question 13, as shown Figure 9-10, we see an increasingly high percentage of respondents rating the importance as either low or not relevant (39%) and no respondents rated it as critical or very important.

9.5 Descriptive statistics: ranking of sustainability criteria

The third part of the questionnaire asked respondents to explicitly state their perception of the importance of each of the factors identified in the literature as indicators of sustainability.

The questionnaire listed in Part III (as per Appendix C) asked respondents to rank the factors in order of relative levels of importance to the concept of sustainability in engineering, from most important to least important (maximum rank is 5) using a 5-point Likert ranking scale. The raw data provided by each respondent was used to calculate the mean of each factor. In this scheme, numeric scaling values are used. The calculation of the mean and standard deviation of all factors is shown in Table 9-3, where factor "energy efficiency" (variable 3) was ranked as the most important to the concept of sustainability in engineering.

Variable	Name	Rank	N	Missing	Mean	SD	Min	Max
v3	**Energy efficiency**	**1**	**88**	**12**	**4.5341**	**0.9216**	**2**	**5**
v14	**Global warming**	**2**	**92**	**8**	**4.12**	**1.118**	**1**	**5**
v13	**Pollution control**	**3**	**94**	**6**	**4.117**	**1.144**	**1**	**5**
v29	**Time scale-design**	**4**	**91**	**9**	**4.099**	**1.136**	**1**	**5**
v18	**Inclusivity**	**5**	**98**	**2**	**4.0918**	**0.9091**	**2**	**5**
v15	**Economic viability**	**6**	**95**	**5**	**4.084**	**1.078**	**1**	**5**
v17	**Corporate responsibility**	**7**	**92**	**8**	**4.076**	**0.963**	**2**	**5**
v7	**Health and wellness**	**8**	**86**	**14**	**4.058**	**1.022**	**2**	**5**
v26	**Integration**	**9**	**87**	**13**	**4.057**	**1.124**	**2**	**5**
v1	Resource availability	10	94	6	3.947	1.158	2	5
v8	Institutional	11	94	6	3.883	1.056	2	5
v4	Employment	12	89	11	3.854	1.202	1	5
v24	Collaboration	13	85	15	3.835	1.143	1	5
v21	Carrying capacity	14	95	5	3.768	1.036	2	5
v20	Ethics	15	98	2	3.755	1.016	2	5
v27	Technology end use	16	93	7	3.753	1.176	1	5
v32	Engineer's involvement	17	98	2	3.745	1.16	1	5
v16	Affordability	18	96	4	3.7187	0.9482	2	5
v5	Work atmosphere	19	97	3	3.701	0.9261	2	5
v31	Design intentions	20	93	7	3.699	1.187	1	5
v2	Quality of life	21	88	12	3.693	1.168	1	5
v28	Intergenerational equity	22	98	2	3.663	1.157	1	5
v10	Environmental manufacturing	23	97	3	3.649	1.1	1	5
v12	Stress at work	24	60	40	3.633	1.551	1	5
v23	Performance of the system	25	95	5	3.611	1.065	2	5
v22	Training	26	80	20	3.6	1.327	1	5
v19	Waste hazards	27	71	29	3.592	1.39	1	5
v25	Ozone layer depletion	28	100	0	3.58	0.9763	2	5
v6	Social acceptance	29	93	7	3.538	1.265	1	5
v9	Low entropy	30	98	2	3.531	1.229	1	5
v11	Adaptability	31	99	1	3.414	1.125	1	5
v30	Organizations	32	99	1	3.313	1.368	1	5

Table 9-3: Descriptive statistics by factor ranked by mean in descending order

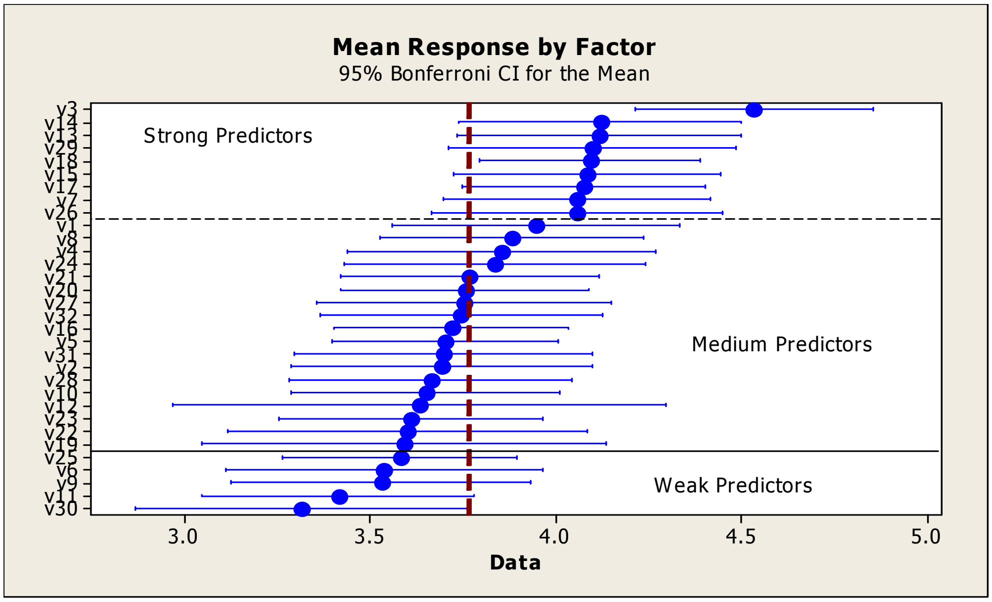

Figure 9-11: Mean and 95% Bonferroni corrected confidence intervals.

Despite the ongoing debate on Bonferroni correction usage in data analysis (Moran, 2003; Nakagawa, 2004), it was used in this analysis to study correlation relationships of group differences (Cabin and Mitchell, 2000; Curtina and Schul, 1998; Demšar, 2006). The rank order is maintained, however, the boundary of the confidence intervals suggest some breaks. Since we are making many multiple comparisons between means, we are increasing the role of chance. To mitigate this problem, the confidence intervals have been adjusted using the Bonferonni Correction. This correction generates a corrected alpha, based on the total number of comparisons and is reflected in Figure 9-11.This approach is superior to a simple ranking, as it also takes into account the variability of each response. Furthermore, we notice that weak and strong intervals largely do not overlap, inFigure 9-11, where significant differences exist between means where the confidence intervals do not overlap. This would separate the strong from the weak predictors and leaves a large number as medium predictors, which the vertical line delineates.

9.5.1 Differences in the mean responses by factor

With ordinal data, the means of the responses become an ideal dependent variable. To compare multiple means, a one-way analysis of variance was conducted on all 32 factors. The results shown in Figure 9-11indicate significant difference between some of the means $F(31,2901)$ $p < .001$. The results of the ANOVA alone do not tell us which means are significantly different from each other. However, we can use the boundaries of the 95% confidence intervals to look for reasonable points in the factors that suggest more or less contribution. The rank order is maintained, however, the boundary of the confidence intervals suggest some breaks. Since we are making many multiple comparisons between means, we are increasing the role of chance. To mitigate this problem, the confidence intervals have been adjusted using the Bonferonni Correction (Klaus et al., 2009). This correction generates a corrected alpha based on the total number of comparisons and is reflected in Figure 9-11. This approach is superior to a simple ranking as it also takes into account the variability with each response. Furthermore, we notice the weak and strong intervals largely do not overlap, in Figure 9-11, where significant differences exist between means where the confidence intervals do not overlap. This would separate the strong from the weak predictors and leaves a large number as medium predictors, which the vertical line delineates.

Rank		Factor	Percentage Choosing 5	Mean Rank	Mean	Rank Gap
1	v3	Energy efficiency	76.14	1	4.5341	0
2	v13	Pollution control	52.13	3	4.117	1
3	v29	Time scale – design	51.65	4	4.099	1
4	v14	Global warming	50	2	4.12	2
5	v26	Integration	49.43	9	4.057	4
6	v15	Economic viability	48.42	6	4.084	0
7	v12	Stress at work	46.67	24	3.633	17
8	v1	Resource availability	44.68	10	3.947	2
9	v7	Health and wellness	43.02	8	4.058	1
10	v4	Employment	42.7	12	3.854	2
11	v17	Corporate responsibility	41.3	7	4.076	4
12	v19	Waste hazards	40.85	27	3.592	15
13	v18	Inclusivity	38.78	5	4.0918	8
14	v8	Institutional	38.3	11	3.883	3
15	v22	Training	37.5	26	3.6	11
16	v27	Technology end use	36.56	16	3.753	0
17	v24	Collaboration	35.29	13	3.835	4
18	v32	Engineers involvement	32.65	17	3.745	1
19	v31	Design intention	32.26	20	3.699	1
20	v2	Quality of life	31.82	21	3.693	1
21	v9	Low entropy	30.61	30	3.531	9
22	v28	Intergenerational equity	29.59	22	3.663	0
23	v21	Carrying capacity	28.42	14	3.768	9
24	v20	Ethics	27.55	15	3.755	9
25	v6	Social acceptance	26.88	29	3.538	4
26	v23	Performance of the system	26.32	25	3.611	1
27	v10	Environmental Manufacturing	25.77	23	3.649	4
28	v30	Organisations	25.25	32	3.313	4
29	v16	Affordability	22.92	18	3.7187	11
30	v5	Work atmosphere	20.62	19	3.701	11
31	v11	Adaptability	18.18	31	3.414	0
32	v25	Ozone depletion	17	28	3.58	4

Table9-4: Importance ranking by percentage of respondents selecting the factor with the highest score.

9.5.2 Ranking factors by percent

An alternative approach to identifying the most important factor recorded by respondents to the concept of sustainability in engineering (from amongst the 32 factors offered in the questionnaire) is to select the factors which have at least 50% of respondents choosing the top agreement choice of the likert scale of 5. Ultimately, the factors to be classified as significant needed to score a value of 50% or more. Once the percentage rating was calculated, the factors were ranked. The following factors have at least 50%, in order of ranking:

1. V13: Pollution control 52.13 %
2. V29: Time scale-design 51.65 %
3. V14: Global warming 50.00 %

These factors also appear as 3 of the top 4 predictors from the mean analysis. Table9-4 ranks the factors based on percentage in the top choice and compares them to the rank using the means. Furthermore, the column "Rank Gap" shows the difference between the ranks of both methods. There is strong agreement using both methods, especially in the top category of strong predictors, with the exception of factor 12, which has a much lower mean value than percent choosing likert scale of 5 (17 point gap in rank). Due to the strong agreement between both the means and percentage methods, the mean ranking will be used and the top 9 factors, as identified in Figure 9-11 will be used as strong predictors of sustainability in engineering. Internal Reliability: Reliability for the scales, in terms of internal consistency, was estimated using Cronbach's alpha coefficient, which examines the factors' correlation with the total values. Cronbach's coefficient α provides one way to index the internal consistency of the items in a test (Cronbach, 1951; Graham and Lilly, 1984; Reynaldo and Santos, 1999). Values greater than 0.7–0.8 indicate a strong correlation of scale items and suggest that the scale is measuring a single underlying dimension. For this dataset, Cronbach's coefficient α is 0.83 with the results proving that all the scales presented an adequate reliability, due to the fact that Cronbach's α was ≥ 70%. The internal consistency was assured since generally α as a value of 60% is considered adequate (Hair et al., 1995). This means that the scales are consistent and suggest strong internal reliability. Table 9-5 shows the item total correlation by factor where any correlations below 0.30 are highlighted. A correlation of 0.30 is used as the lowest acceptable value in establishing relationships. Correlations below 0.30 suggest poor cohesiveness for predicting an overall sense of sustainability in engineering. Seven factors have been highlighted as not meeting this lowest threshold.

Factor	Item Total Correlation	Rank	Factor Description
v1	0.35	21	Resource availability
v2	**0.53**	8	**Quality of life**
v3	0.49	9	Energy efficiency
v4	0.39	19	Employment
v5	0.36	20	work atmosphere
v6	0.46	13	Social acceptance
v7	**0.62**	2	**Health and wellness**
v8	0.22	28	Institutional
v9	0.26	27	Low entropy
v10	**0.56**	5	**Environmental Manufacturing**
v11	0.14	30	Adaptability
v12	**0.59**	3	**Stress at work**
v13	0.35	22	Pollution control
v14	0.43	15	Global warming
v15	**0.54**	7	**Economic viability**
v16	0.32	24	Affordability
v17	**0.63**	1	**Corporate responsibility**
v18	0.45	14	Inclusivity
v19	**0.59**	4	**Waste hazards**
v20	0.27	26	Ethics
v21	0.21	29	Carrying capacity
v22	0.40	17	Training
v23	0.33	23	Performance of the system
v24	0.08	31	Collaboration
v25	0.48	10	Ozone Layer Depletion
v26	0.47	12	Integration
v27	0.48	11	Technology end use
v28	0.42	16	Intergenerational Equity
v29	**0.56**	6	**Time scale- Design life cycle**
v30	-0.07	32	Organizations
v31	0.40	18	Design intentions
v32	0.31	25	Engineer's involvement

Table 9-5: Item total correlations by factor

Items 24, 30 and 11 correlate the least (Collaboration, Organizations and Adaptability) either because of poor question wording or because they measured another construct (or both).Conversely, the items which correlate highest with the total mean are bolded and have been marked based on correlations above 0.50. This level is more arbitrary that the lower cut-off, but the example suggests corporate responsibility and 'health and wellness' are among the biggest contributors to sustainability in engineering.

9.5.3 Factor analysis

The use of factor analysis followed by a varimax rotation to analyse original pool of data is well known (Charles and Fyfe, 2000; Davidson, 1975; Schutte et al., 1998; Tufan and Cemil, 2007). Item total correlation is one way of establishing multivariate relationships and is a precursor to factor analysis, which takes into account simultaneous correlations between variables. Table 9-6 is the result of a factor analysis using principal components extraction and rotating the factors using the Varimax Rotation (Hill and Lewicki, 2007; Merklea et al., 1998). The first factor from the factor analysis above (which contains the variable factors v3, v23, v4, v12,v17 and v16) accounts for the most variance, at 31%. A common practice in factor analysis is to then attempt to give a name to the factor based on the variables which have a high loaded value (usually > 0.4).

				Factor (Component)						
Variable		**Mean Rank**	**Item Total Rank**	1	2	3	4	5	6	7
6	Social acceptance	6	**13**	0.712	0.206	0.281	-0.03	-0.05	0.061	-0.021
14	Global warming	14	**15**	0.707	0.11	-0.105	0.188	0.331	0.023	0.014
32	Engineer's involvement	32	**25**	0.57	0.063	0.111	0.015	-0.307	0.491	-0.057
19	Waste hazards	19	**4**	0.485	-0.119	0.421	0.278	0.29	-0.03	0.076
15	Economic viability	15	**7**	0.388	0.285	0.338	0.233	-0.088	0.31	0.158
13	Pollution control	13	22	-0.048	**0.715**	-0.046	0.222	0.267	-0.041	0.038
2	Quality of life	2	8	0.354	**0.585**	0.208	-0.026	0.203	0.209	-0.045
22	Training	22	17	0.375	**0.571**	0.191	0.023	-0.112	0.003	-0.089
27	Technology end use	27	11	0.099	**0.454**	0.304	-0.221	0.439	0.283	-0.095
17	Corporate responsibility	17	1	0.351	**0.398**	0.381	0.325	0.174	0.034	0.277
29	Time scale- Design life cycle	29	6	0.201	0.383	0.716	0.024	0.048	0.087	0.024
26	Integration	26	12	0.031	0.155	0.651	-0.055	0.001	0.518	-0.017
12	Stress at work	12	3	0.032	-0.012	0.634	0.156	0.457	-0.025	-0.108
7	Health and wellness	7	2	0.359	-0.021	0.529	0.338	0.206	0.101	0.073
18	Inclusivity	18	14	-0.033	0.017	0.112	**0.866**	0.107	0.062	0.003
5	Work Atmosphere	5	20	0.213	0.125	-0.001	**0.749**	-0.018	0.077	-0.201
10	Environmental Manufacturing	10	5	0.091	0.499	0.132	**0.602**	-0.073	0.273	-0.018
23	Performance of the system	23	23	0.042	-0.372	0.245	**0.417**	0.397	0.155	0.25
3	Energy efficiency	3	9	0.279	0.303	0.014	-0.018	0.705	-0.049	0.188
4	Employment	4	19	-0.01	0.087	0.231	0.041	0.619	0.007	-0.16
31	Design intentions	31	18	0.185	0.006	0.06	0.148	0.022	**0.779**	-0.029
25	Ozone Layer Depletion	25	10	-0.067	0.472	0.196	0.138	0.115	**0.526**	0.27
16	Affordability	16	24	-0.108	-0.003	0.002	0.157	0.51	**0.516**	0.052
28	Intergenerational Equity	28	16	0.246	0.119	0.193	0.184	0.173	0.136	-0.71
1	Resource availability	1	21	0.338	0.108	0.194	-0.011	0.119	0.212	0.637
	EigenValues			6.72	2.06	1.86	1.55	1.51	1.26	1.01
	% of Variance			26.88	8.25	7.44	6.20	6.05	5.04	4.05
	Cumulative %			26.88	35.12	42.57	48.77	54.82	59.85	63.90

Table 9-6: Rotated factor pattern

Note: The term factor, in the context of a Factor Analysis, refers to a combination of variables which cluster together. This is not to be confused with the term factor (criteria/indicator), which was given to the 32 variables in assessing overall sustainability in engineering.

The high loading variables have been bolded and are ordered from most to least. The variables v3 and v4 (energy efficiency, employment) and variables v17 and v16 (corporate responsibility and affordability) load highly and appear to have something in common (based on the names of the variables). The subsequent factors from the factor analysis (factors 2-7) are more difficult to interpret, as the variables with a high loading on each factor don't appear to have much in common.

Variable		Mean Rank	Item Total Rank	Factor (Component) 1	2	3	4	5	6	7
6	Social acceptance	6	**13**	0.712	0.206	0.281	-0.03	-0.05	0.061	-0.021
14	Global warming	14	**15**	0.707	0.11	-0.105	0.188	0.331	0.023	0.014
32	Engineer's involvement	32	**25**	0.57	0.063	0.111	0.015	-0.307	0.491	-0.057
19	Waste hazards	19	**4**	0.485	-0.119	0.421	0.278	0.29	-0.03	0.076
15	Economic viability	15	**7**	0.388	0.285	0.338	0.233	-0.088	0.31	0.158
13	Pollution control	13	22	-0.048	**0.715**	-0.046	0.222	0.267	-0.041	0.038
2	Quality of life	2	8	0.354	**0.585**	0.208	-0.026	0.203	0.209	-0.045
22	Training	22	17	0.375	**0.571**	0.191	0.023	-0.112	0.003	-0.089
27	Technology end use	27	11	0.099	**0.454**	0.304	-0.221	0.439	0.283	-0.095
17	Corporate responsibility	17	1	0.351	**0.398**	0.381	0.325	0.174	0.034	0.277
29	Time scale- Design life cycle	29	6	0.201	0.383	0.716	0.024	0.048	0.087	0.024
26	Integration	26	12	0.031	0.155	0.651	-0.055	0.001	0.518	-0.017
12	Stress at work	12	3	0.032	-0.012	0.634	0.156	0.457	-0.025	-0.108
7	Health and wellness	7	2	0.359	-0.021	0.529	0.338	0.206	0.101	0.073
18	Inclusivity	18	14	-0.033	0.017	0.112	**0.866**	0.107	0.062	0.003
5	Work Atmosphere	5	20	0.213	0.125	-0.001	**0.749**	-0.018	0.077	-0.201
10	Environmental Manufacturing	10	5	0.091	0.499	0.132	**0.602**	-0.073	0.273	-0.018
23	Performance of the system	23	23	0.042	-0.372	0.245	**0.417**	0.397	0.155	0.25
3	Energy efficiency	3	9	0.279	0.303	0.014	-0.018	0.705	-0.049	0.188
4	Employment	4	19	-0.01	0.087	0.231	0.041	0.619	0.007	-0.16
31	Design intentions	31	18	0.185	0.006	0.06	0.148	0.022	**0.779**	-0.029
25	Ozone Layer Depletion	25	10	-0.067	0.472	0.196	0.138	0.115	**0.526**	0.27
16	Affordability	16	24	-0.108	-0.003	0.002	0.157	0.51	**0.516**	0.052
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1	Resource availability	1	21	0.338	0.108	0.194	-0.011	0.119	0.212	0.637
			EigenValues	6.72	2.06	1.86	1.55	1.51	1.26	1.01
			% of Variance	26.88	8.25	7.44	6.20	6.05	5.04	4.05
			Cumulative %	26.88	35.12	42.57	48.77	54.82	59.85	63.90

Table 9-7: Factor matrix

1.5.0 Mean as substitute value for missing values

The previous factor analysis used only responses with no missing values. Unfortunately, this excluded the majority of the data, leaving only 24 cases with no missing values. The result is an unstable factor matrix, which would likely change with the addition of more complete responses. An alternative approach shown below is to substitute the mean value of the factor variable for missing values. The resulting factor matrix is shown below in Table 9-7. We now see a slightly different set of variables for the first factor than what we saw from the factor analysis above. In attempting to name this factor, it appears that each variable (v6, v14, v32, v19 and v15) does not appear to have much in common.

9.5.4 Cluster analysis

Another multivariate technique was used to see if there were any logical patterns in the responses. In addition to factor analysis, the results are more difficult to interpret than factor analysis as defining the clusters is a more subjective process. I have attempted to generate five main clusters with the aim of covering the five main criteria: social, economic, ecological, technological and time. A likely cause for the poor factor structure is the possibility of different populations being represented in the dataset in terms of age group and professional persuasion. To assess differences in sustainability in engineering importance ranking, a composite score will be generated from the top nine factors by taking the total of the top nine factors, making the highest score a 45. A dendogram of the results are shown inFigure 9-12. There were some similarities to the factor analysis. For example, we see factors 2,7,29 and 26 clustering together (quality of life, health and wellness, time scale - design life cycle and integration), as they do in the factor analysis. Also, 5, 18 and 10 cluster together (work atmosphere, inclusivity and environmental manufacturing) and are all on the same factor. This is encouraging as it corroborates the factor structure and provides more evidence for these as legitimate clusters.

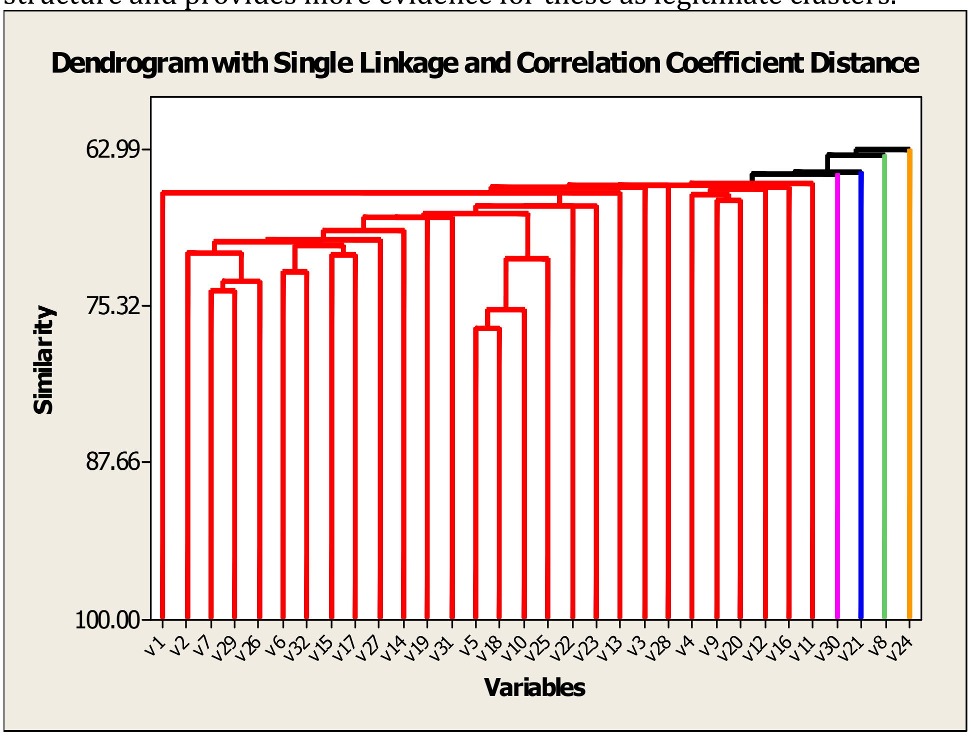

Figure 9-12: Cluster Analysis

9.6 Explanatory open-ended questions

In the next few sections it is the intention of the author to keep all the interview quotes in original English only adjusting punctuation.

Interview Question 1 asked: What is the status of sustainability in your field of engineering, what are its characteristics or attributes? Is it a utopian state or pseudo ideal process? Is it a strategy? Is it real or an illusion? Responses included:

Engineer 1:*"Sustainability, as a concept, applies integration. It is a system comprising humans and the rest of nature. We often quarrel at work with colleagues as to whether it's real.*"

Engineer 34: *"It's a structure and operation of society, economy, nature, and law, reinforced to promote harmony."*

Engineer 55: "*We try to follow internal procedures."*

Engineer 89: *"The natural connection of ecosystem and biodiversity."*

Summary: to a great extent it appears that sustainability is as a process of discussions and opposing to a state condition;
"it is more than ensuring ecological integrity and the standard of living. It is about the quality of life and thus addresses the ultimate questions about meaning in life". (Fricker, 1998)

Interview Question 2 asked: Can sustainability as a process be measured? What are the key indicators and criteria? What are its characteristics and challenges? What tangible information and contextual factors affect decision makers when making sustainability decisions and how do these affect decision outcomes? Responses included:

Engineer 2:*"We can rate our progress, but not measure sustainability. Sustainability in engineering is about justifying the use of resources, by validating social, economic and ecological standards."*

Engineer 31: *"Benchmarking is a useful tool to quantify the sustainability of an engineering project."*

Engineer 87: *"Measuring sustainability is not possible. It is not a quantity and hence we pace it using ambitious targets. Criteria is always an easy way to do that."*

Summary: The opinion is open on measurement of sustainability whilst, as (Fricker, 1998), had suggested,

> "indicators are limiting measures reflecting unsustainability and survival rather than sustainability. Their main value is in indicating direction of change rather than a desirable state.."

Interview Question 3 asked: How do we improve the design processes to include sustainability? Where do these complex issues leave engineers and designers? How would engineers apply sustainability to preliminary designs?

Engineer 11:*"Train people, provide Continuing Professional Development (CPD) in sustainability principles."*

Engineer 16: *"Education is pivotal."*

Engineer 44: *"We follow our internal design policies including Australian standards or ISO 14000 environmental management standards."*

Engineer 54: *"Indicators can provide crucial guidance for decision-making in a variety of ways."*

Engineer 68: *"Tailoring an approach to the specific needs."*

Summary: In practice, engineers, corporations and institutions equally face daily the many and multiple conflicting sustainability objectives to be balanced despite the persistent definitional ambiguities associated with sustainability. Design engineers must take into account indicators or indices from the vast body of work. A common criticism of indices has been that their use results in a loss of information (Young, 1997). However, if all the sub-indicators have credibility (value), then a user can examine the detailed components of an index.

Interview Question 4 asked: In your opinion, what is the current state of sustainability definitions' strengths and weaknesses? Responses included:

> **Engineer 5:** *"I cannot name one definition but I know that it's about saving the future generations."*
>
> **Engineer 9:** *"Need to use fewer resources."*
>
> **Engineer 13:** *"Considering others."*
>
> **Engineer 20:** *"Integration of economic, social environmental issues in decision and policy making at all levels."*
>
> **Engineer 76:** *"We compiled our own definition at work; in summary, it is compliance and preservation."*
>
> **Engineer 80:** *"I don't agree with most definitions. To me, sustainability is doing the current job and considering efficiency."*
>
> **Engineer 98:** *"As an engineering consultant, time means money. If I can reduce my operating costs, it will most likely get a tick."*

Summary: Despite the fact that the overall results of the above question failed to explicitly and coherently, define sustainability form an engineering perspective, indeed the engineers arguments just presented attempts of the personal "me" benefit doctrine. Given the inclusivity of sustainability "me" factor must be abandoned.

Interview Question 5 and 6 asked: What level of sustainability assessment exists among engineering system? What is the state of sustainability capabilities in engineering? Responses included:

> **Engineer 5:** *"The market is full of tools and frankly we do not use any of them. We design projects using client design of objectives, and nowadays, this would typically include alliance with sustainable development"*
>
> **Engineer 9:** *"I have had training in LCA, EMS modules and Simpro, however we use an Excel spreadsheet to generate multi-criteria analysis."*
>
> **Engineer 13:** *"Our company has a Corporate Social Responsibility (CSR) manual that includes key assessment criteria."*
>
> **Engineer 16:** *"The issue with software tools is that they have not matured and are limited in terms of offering, I always come across situations where the tool does not support a particular discipline."*
>
> **Engineer 20:** *"If engineers were provided with the incentive, I think they would have an opportunity to contribute to sustainability in their work place."*

> **Engineer 28:** *"I have found software tools far too complicated and I have not been able to provide the funding nor the time to send anyone to train my staff."*

Summary: The above responses are no surprise if we consider the literature. To clarify the definitional ambiguities associated with sustainability, we have resorted to plurality where there are four quite distinct categories of measurement: people, nature, economy, and society, although early literature focused on the economy, with its productive sectors providing both employment and desired consumption and wealth. The economy provides the incentives and the means for investment as well as funds for environmental maintenance and restoration (Solow, 1993).
Most recently, the focus has shifted to people with an emphasis on human development, increased life expectancy, education, equity, and opportunity with global drivers like the UN General Assembly 2000 and the International Monetary Fund Organisation. Finally, there were also calls to develop society emphasizing the well-being and security of national states, regions, and institutions and the social capital of relationship and community ties (Esty et al., 1998; Putnam, 1995; Varshney, 2002; Woolcock, 1998).

Interview Question 7 asked: What is the engineering perspective on applied sustainability, what are the most important attributes, and how do we try to improve it? How strongly are sustainability values embedded into engineering? To what extent do criteria satisfy the sustainability appraisal? Responses included:

> **Engineer 1:** *"It seems to be rather easy to say what an ideal indicator should look like, but it is much more difficult to find them,"*
>
> **Engineer 2:***"Existing management practices create ''silos'' where each dimension is looked at separately,"*
>
> **Engineer 5:** *"We, in the engineering industry, need a practical measurement that takes environmental considerations into account as a base for decisions on future projects, not some philosophy,"*
>
> **Engineer 7:** *"Emission standards alone are not sufficient to implement sustainability,"*
>
> **Engineer 15:** *"Indictors and standards change rapidly undermining their usefulness,"*
>
> **Engineer 22:** *"We run environmental risk analysis but I believe it is fragmentary and inconclusive,"*
>
> **Engineer 25:** *"We need to include societal risk assessment,"*
>
> **Engineer 26:** *"Indicators cannot measure everything! Difficult trade-offs are always required, ""*
>
> **Engineer 31:** *"Some of the indicator systems in the market have a complex mathematical theory which makes them difficult to manage."*
>
> **Engineer 33:** *"I think they lack practicality, compatibility, and scope in engineering. I would like to see universally-accepted formula for creating an indicator framework."*

> **Engineer 36:** *"Getting information for indicators takes time as well as financial constraints."*

> **Engineer 50:** "*Data availability is always an issue; there is need for institutional support for data collection."*

Summary: Furthermore, many papers dealing with the subject of indicators provide a list of ideal (selection) criteria based on the purpose of the required set (IChemE., 2002; Institution of Engineers Australia, 1992; OECD, 1993, 2003). We have summarised what we can refer to as a wish list of attributes, as shown in Table 9-8. These coincide with the interview commentaries.

Clear in content: easily understandable, transparent;
Policy relevant;
Theoretically well founded (scientific basis);
Sensitive to (human induced) changes, show changes in time;
Technically measurable (reproducible, reasonable costs, etc.);
Appropriate to scale (in time as well as geographically and/or spatially);
A wider significance than its immediate meaning.

Table 9-8: Core set of criteria (Malkina-Pykh, 2002)

9.7 Criteria development discussion

Sustainability assessment is a valid domain of study , as discussed in Chapter 3, however sustainability criteria progression and development can be viewed as either "evolution or revolution". This raises the need for an central method of measurement (Bossel, 1999). This series of interviews highlighted the variation of opinion on 32 indicators. Furthermore, I believe in order for any serious consideration on the topic to occur, the profile of the discussion must be raised outside the academic arena. However, before developing the ranking of the indicators, a clear definition of what constitutes a sustainability criterion must be addressed. This appears to be difficult due to the fragmentation of criteria. This is not necessarily an oxymoron, on the contrary, this is perceived as the stimulus to the discussion theme of advancing sustainability in an engineering context. Although it is recognized that no single process can describe a universal engineering approach, the reflections from this chapter have provided a roadmap on the indicator process that yielded the following key points:

- the key to successful implementation is integration with existing engineering systems;
- indicators should complement, not replace existing systems;
- weakness is in linking information to decision making;
- significant time will be required to develop indicators appropriate to the engineering context

As demonstrated in Figure 7-4, criteria at lower levels of the engineering design hierarchy must be tied to indicators at higher levels. Although the indicators do not necessarily need to be tightly bound together, they should be related. This opinion is also supported by (Searcy et al., 2005) where it was reported that applying the principles of sustainability has to become an essential part of doing business; in addition, any system of indicators must be linked to the business planning process. This may be accomplished through a design based on a hierarchical approach that also illustrates linkages between the indicators and incorporates existing measures.

9.8 Conclusion

Application of sustainability in engineering is not confined to one area; it is cross-fertilised across many interdisciplinary and trans-disciplinary boundaries through interconnectedness. The most important factors for the concept of sustainability in engineering, in order of importance are:

- Energy efficiency,
- Global warming,
- Pollution control,
- Time scale-design life cycle,
- Inclusivity,
- Economic viability,
- Corporate responsibility,
- Health and wellness.
- Integration

Factor importance was determined using the lower bounds of the Bonferonni Corrected 95% confidence intervals. The lower bounds of these 9 factors suggest them to be of greater importance that the remaining 23 factors. Only energy efficiency was rated as significantly more important that the other top 8 factors. The importance of the factors was also corroborated by ranking the factors based on the percentage of respondents who ranked the factor as critical (the highest choice of 5). Seven of the same 9 factors were also identified using this method (*Inclusivity* and *Corporate* were not). The internal reliability of the questions were high, Cronbach's alpha coefficient = 0.83 suggesting overall the questions to be a consistent measure. The correlation between some factors and the total correlation (Item-total correlation) was very low, suggesting these items do not gather consistent and reliable responses from the participants. These poorest correlating items (*Organizations, Collaboration* and *Adaptability*) all had item-total correlations below .15. The factors: *Institutional, Low entropy, Ethics, Carrying capacity* had item-total correlations below .30, so had medium to low reliability levels. Using only items with item-total correlations above 0.30, a factor analysis using Varimax Rotation was conducted to attempt and identify underlying structures to the responses. The initial factor analysis was conducted using a pair-wise deletion method, where only cases which did not contain missing values were used. Unfortunately, this left responses from only 24 out of the 100 participants and makes the sample size too small to extract meaningful factors. Next, the mean values for the factors were substituted in place of the missing values and 7 factors were extracted which explains 64% of the variation in all responses. The first factor explains around 28% of the variation and has the following variables loading highly on it: social acceptance, global warming, and engineer’s involvement and waste hazards loading highly on it. There doesn’t appear to be much similarity between any of these variables, making naming and interpreting this factor difficult. A cluster analysis on the means was also performed to uncover structures in the data. The results were more difficult to interpret than the factor analysis; however it did identify some of the same groups of factors as the factor analysis. For now, the results of the factor analysis are preliminary and may be used for future research from larger samples with fewer missing values.

> "However, the fact remains that building support for an initiative is critical if it is to succeed in changing attitudes toward sustainability"(Hasna, 2009f)

A potential cause for a failure to find a strong underlying structure in the data may be due to many of the respondents (49%) reporting sustainability policy in engineering as either of low importance or not relevant. With close to a majority reporting sustainability in engineering as of such low-importance, their responses to factors that make up sustainability in engineering might be less relevant. The most salient demographic difference which emerged was the priority of *stress at work*. Respondents with less education (less than a college education) all rated this factor as critical. It was rated as 51% higher in importance than those with a higher education. One of the possibilities to operationalise the concept of sustainability is to utilise designed sustainability indicators and indices able to monitor the pressure on the status of engineering work. According to Fricker (1998)

> "The main value of indicators is indicating direction of change rather than a desirable state".

Obtaining consensus on indicators characterisation has been challenging; in fact, it remains unknown at what stage of engineering work the indicators ought to be engaged in decision-making (Dovers, 2001). This is what I aimed to achieve with this survey, as a tool to flesh out issues, but it is not a complete solution for sustainability in engineering, by any means. The more information becomes available, the more it will enable us to anticipate any impending change, to establish priorities, to formulate adequate strategies.

> "Sustainability in engineering involves incorporating the needs of users; it requires participation, community involvement, transparency of decisions, and consideration of all affected stakeholders"(Hasna, 2009f)

In this chapter we hope to have provided insight that relates to sustainability discussion in engineering

Chapter 10. Conclusion and Implications

10.1 Outline

A fitting opening paragraph to this concluding chapter might be to consider an opening question why is sustainability philosophy being negotiated in an engineering dissertation? Engineering philosophy today has an important role to play in sustainability enlightenment. Because through philosophy we rationalize the world as it is. Philosophical principles allow easier engagement with sustainability. What direction should the engineering profession be driving towards?

10.2 Introduction

This thesis was intended to begin a review and discussion on sustainability philosophy in an engineering context. The studies were undertaken for a science perspective. This was achieved through both a theoretical and practical analysis. It was found that sustainability in engineering is not one thing per se; rather, its contextualization transpires through integration of multidisciplinary relationships. So, what is this mechanism for this contextualization? A brief response would be in view of the fact that contextual information (e.g. constraints, history, developments, resources) is usually the evidence required to translate theory into practice (Glasgow and Emmons, 2007). Similarly, knowledge of sustainability is necessary, but usually insufficient, for behaviour change (Ferris et al., 2001), given that a large gulf remains between what we know about sustainability and what we practice (Davis et al., 2003). Therefore, the contextualizations of the research questions: "sustainability philosophy in engineering" occurs through learning and integration of the definitions of sustainability, its dimensions, history, development, direction, strategy, assessment, measurement, criteria, indicators, constraints, restraints, theories, practices, software tools, philosophies, perceptions and attitudes. In this approach, the work was done attempting to pose a set of ideas and connotations on the expansive sustainability science in the engineering context. Hence the profession needs to consider

> "minimizing anthropogenic perturbations to natural cycles, especially cycles of the key elements (carbon, nitrogen, phosphorous, and sulfur) of biological life" (Swearengena and Woodhouseb,2003)

Furthermore, this highlights the research findings from definitions to operability. Thus far, what is revealed are a plethora of factors that act as enablers. These cross-cutting factors must be accounted for when pursuing the research questions; the attributes of these factors spread across many fields. Hence, as concluding remarks, I would like to utilise the questions raised by (Flyvbjerg, 2001) in terms of the research contributions: (1) where are we going and why is sustainability in engineering important? It is important because its very absence is uncertainty; we as humans want to believe that the world will last indefinitely. Therefore, the concept of sustainability had assumed a central place in society (Hasna, 2009e). According Ouda, (2008) Many of the long established engineering practices “no longer hold true, most of current practicing engineers do not know the long term implications of their practice”. Accordingly, current sustainability practices in engineering are influenced by environmental regulations predominantly minimization refer to the ISO14040 series for detailed information.

Fundamentally, in this thesis, I do not claim to have found the ideal or ultimate description of applied sustainability, or claim final authority. I have provided a contextual understanding to highlight the need to have sustainability considered in engineering thinking. In an ideal utopian world, 100% of recycling is achievable, however we live in a non-ideal world, where it is impossible in engineering terms to achieve 100% recycling, which is why energy input is added to the system to counter entropy as per the second law of thermodynamics. Also, the natural ecology cannot be sustained without photosynthesis. Hence, indefinite sustainability is not physically probable. Therefore, when we define sustainability, it must be defined within the context of time, since everything is sustainable in context within limits and boundary conditions. As it is possible to have a subjective reason for defining sustainability, it is also possible that "sustainable development is in real danger of becoming a cliché like appropriate technology, a fashionable phrase that everyone pays homage to but nobody cares to define" (Lélé, 1991). These recommendations may serve as a basis for continuing dialogue in this area. In order to respond to these challenges no discussion on sustainability would be complete without mention of the one sustainability philosophy two distinct views, i.e. the pessimism of neo-Malthusians is a sharp contrast with the optimism of cornucopians. According to Malthusians sooner or later population will outgrow natural resources[1]. This is described in the following model;

$$P(t) = P_0 e^{rt} \tag{10.1}$$

The cornucopian school of thought endorses some degree of intractable natural limits to growth and believes through the advancements of technology the world can provide limitless natural resources. However as engineers we view the cornucopian philosophy with a degree of reservations in context of the second law of thermodynamics governs the conversion of energy from one form to another,

$$\partial U = \partial W + \partial Q = \partial W + T\partial S \tag{10.2}$$

Where dU, the change in the internal energy of a system is equal to the sum of the reversible work done on it dW and the heat irreversibly exchanged with the environment dQ = TdS (which is associated with a change in the entropy of the system). Simplifying the second Law: Law of increasing entropy or unidirectional flow of thermal energy, hence no system is 100% efficient. According Atkisson (1995) who reported that we must accelerate our industrial and technological development or the forces we have already unleashed will wreak even greater havoc on the world for generations to come. We cannot go on, and we cannot stop. We must transform. The natural conclusion here, would be one of comprise between the two viewpoints, therefore contemporary engineering philosophy regarding sustainability is ought to subsume all known

[1] Where P_0 = Initial Population, r = growth rate, sometimes also called Malthusian Parameter and t = time.

definitional variations and takes responsibly of the world's finite natural resources in a manner which will not compromise the ability of future generations. Building on this basis as engineers discussing sustainability in design projects, we have proposed the use of criteria for assessment, in this way we remain true to the physical laws that govern our universe as it is impractical to totally reject it all. Since all of our current practices support Malthusian theory. Hence our role is to achieve a net positive outcome, by putting forward a premise of balance and moderation through the assessment against known criteria.

10.2.1 Indicators

> "The context of sustainability cannot be separated from its measurement" (Fricker, 1998).

One of the project objectives was to present sustainability criteria from both the literature survey and interviews with experts for determining how to measure, or evaluate applied sustainability in a reliable way. To this effect, I selected a set of 150 indicators to addresses "sustainability" in the large accepted sense of the word and its complexity. This included looking at the social, environmental, economical technological, time dimensions and their connections. These indicators are effectively an aggregate of the key factors.

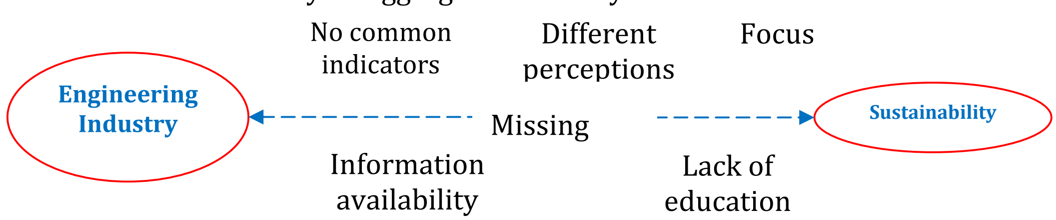

Figure 10-1: Sustainability industry mismatch

Hence, in order to demonstrate the interaction between the industry, and the organisational and the global environment, we determined the importance of the ranking of sustainability indicators which assisted in characterizing, benchmarking or improving purposes. Furthermore, (Farsari and Prastacos, 2002) wrote "indicators are used in everyday life most commonly to alert to a change in a "normal" situation. For example, a red light in the car fuel gauge is an indication of low fuel and so on. Information is essential in everyday life, in engineering and in policy making, in order to make accurate, on time evaluations of a situation and take decisions". In addition, the results of the analysis identified and prioritized the most important indicators in accordance with the concept of sustainability in engineering.

Energy efficiency
Global warming
Pollution control
Time scale-design
Inclusivity
Economic viability
Corporate responsibility
Health and wellness
Integration

Table 10-1: Indicators in order of importance

The results of the interviews presented a large array of expert's opinion, drawn from all areas industry. Upon a closer examination of interviewee's perceptions we can present a simplistic taxonomy of sustainability attitude existing within practicing engineers as shown in Figure 10-2. Furthermore the data analysis, several recurring themes emerged that encompassed social, economic, ecological, technological and time-related dimensions. These criteria represent sustainability. A summary of these indicators, grouped according to the importance ranking, is provided in Table 10-1.

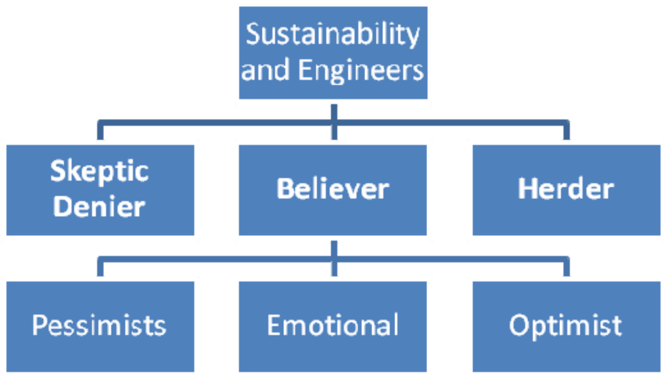

Figure 10-2: taxonomy of philosophy

The alarming results of energy efficiency rating as number one raises more concern about the reason rather than the result, for instance energy efficiency is a quantifiable quality, it is measurable and hence engineers associate it with sustainability. On the other hand inclusivity is rated 13th in importance ranking by percentage of respondents selecting the factor with the highest score. This alludes to the possibility tunnel vision, our society and education system are creating by over specialisation of engineers. Given that sustainability spreads across many boundaries It should be noted that not all of these indicators are clearly reflected in the structure of Agenda 21. However, in order to address the concern of creating ''silos'', indicators need not be listed as an environmental, economic, or social etc… but a cluster of actionable, relevant, credible issues that provide linkages. Furthermore, this provides the drive for linking the indicators to engineering at the operational level to be addressed by a hierarchy of indicators. Yet it could be argued that it is not possible to have a set of generic sustainability indicators, applicable in engineering, due to the vast enormity of activities, and we still do not have the scientific knowledge and technology to implement such sustainability indicators. This thesis, however, supports the idea that it is possible to have a standard set of indicators (i.e. indicators applicable in engineering) and as (Vollmann, 1996) points out, it is better to measure the right things approximately than the wrong ones with great accuracy and precision.

10.2.2 Energy efficiency

The greatest potential for transformative change towards sustainability may lie in improving conversion efficiencies. In analysis of energy efficiency in sustainability Huesemann (2003) reported on the following four reasons why enhancement in -efficiency alone will not be enough to bring about sustainability.

1. **Not easy to change to renewable:**” since foundations of western industrial societies are based on the exploitation of non-renewable minerals and fuels”.
2. **Lasting sustainability:”** Long-term can only be guaranteed if all energy is derived directly or indirectly from the sun”.
3. **Bound by the second law of thermodynamics:** “Human ingenuity and the greatest technological optimism are, which dictates that all industrial and economic activities have unavoidable negative environmental consequences”.
4. **Eco-efficiency is not a reduction environmental impact:** “Unless growth in both population and consumption is restrained, these technological improvements only delay the onset of negative consequences that, as a result, will have increased in severity, thereby reducing our freedom to choose satisfying solutions”.

This reiterates the research question, how can engineers play a positive role in sustainability to eliminate negative consequences? Unquestionably, the engineering profession can make significant contributions via improvements of technical efficiencies. Providing more with the same amount of energy consumed is generally the least expensive, most benign deployable pathway to work towards sustainability (Hasna, 2009d). The world has saved far more energy (since 1973) through improved efficiency than it has gained from all new sources (Flavin and Durning, 1988). Each kWh of electricity conserved saves 0.4 kg of coal and 1.0 kg of CO_2 and 15 g of SO_2 from a coal power plant. According to (Hawken et al., 1999), the whole economy is less than 10% as energy-efficient as the laws of physics permit. This is perhaps what (Alexander, 1964) described as forms that badly fit their context. Fitness is the relation of mutual acceptability between domains. In a problem of design, we want to satisfy mutual demands which the two make on one another. We want to put the context and the form into effortless contact or frictionless coexistence. Hence, energy efficiency needs to gain attention in the engineering profession. However since thermodynamics is the science of energy efficiency, this science supports the concept of 100% recycling as unfeasibility. Ultimately this advocates that all engineering development and future technologies are bound by these limitations. This theory raises several questions about entropy reduction.

10.3 Change management

Policy change has three levels of increasing depth: changing language, changing thinking, and changing culture (Healey, 1999). However ‘vocabulary’ and ‘thinking’ need to be addressed in engineering sustainability policy and to some extent, a change in culture of the profession. In the context of engineering, it is possible to suggest changes in the language. Perhaps the best way to understand the policy is to review the terms suggested by (Newman, 2003), as illustrated in Table 10-2, where the old style development is characterised by language that is distant from responsibility and sustainability is characterised by language that holds its own change management. Thus, for a sustainability strategy to be better understood, an articulated vocabulary is ultimately necessary in a sustainable world. The use of rainwater tanks and the recycling and reuse of domestic graywater can significantly reduce drinking water demand by 20–

40%, stormwater run-off by up to 35%, and wastewater output by up to 37%, as well as reducing water supply, wastewater, and stormwater infrastructure costs (Christov A-Boal et al., 1995; Coombes and Kuczera, 2003; De Silva et al., 2000; Herrmann and Schmida, 1999; Maher and Lustig, 2002; Mitchell et al., 1999; Okun, 1996; Speers and Mitchell, 2000). For example, barriers to the widespread implementation of recycling, and reuse of wastewater greywater and black water and storm water for both non-potable and potable would first and foremost be due to the lack of policy by governments and more importantly, it was not factored in the initial design assessment of the project. This can be argued as being social barrier attitudes to recycling, however it is clear that social attitudes are by-products of technology (Donnelly and Boyle, 2006). For example, even if society wanted to remain using VHS "Video Home System", the reduction in releases on that platform or phasing out forced society to migrate to DVD "Digital Versatile Disc" and the like. Similarly, with analog TV and digital TV phasing out, CDMA and 3G mobile services, etc. The acceptability of more sustainable alternatives is, thus, heavily dependent on the systemic context of policy.

Old style	Sustainability
Balance Limited impact Competition Acceptable levels of Meeting all statutory requirements Consultation Experts Planning No major effects You can't have development without financial benefit I'm only the Its not my responsibility In the ideal world, Environmental / Social Impact Assessment Its not in the interests of	Net benefit Change Ongoing management Efficiency Inclusive Innovation Design Best Practice Long term Participation/engagement Altruism Repair Enhance Sense of place Sacred Economic performance Externalities Broad based benefit Partnerships I'm Responsible Networks Interdependence Future

Table 10-2: Two approaches to development (Newman, 2003)

10.3.1 Engineering education

Embedding sustainability education in engineering requires addressing engineers' contribution towards net positive outcome by focusing on minimizing negative impacts on the environment and society. Similarly we are not attempting to redefine sustainability it is not new, literature is rich with interpreted meanings and definitions post Brundtland Report whilst these definitions varied linguistically they all share similar nonfigurative, idealistic chic, covering four to six known dimensions[2]. Hence definitional and interpretational meanings directly relate to sustainability assessment. These include converging on protecting the environment and balancing consumption of natural resources. A number of methods were presented in literature, primarily through Educating engineers not limited to energy efficiency, over consumption, this was also suggested by Swearengena and Woodhouseb, (2003).

10.4 Recommendation

This dissertation presented the current state of literature as to establish the gaps in sustainability assessments and strategies, whilst these methods are clearly acknowledged as common sense today; this is the first documented attempt of this commonly known evidence. We have presented of this rational, since a systematic review of this common sense has not existed previously to document understanding of sustainability in engineering context.

Sustainability as a concept we will learn to live with and understand, it is not a single entity. Evaluating sustainability, currently involves a complexity of methodologies employed and a lack of consistency in the results obtained. The indices and metrics reviewed were vague and provided little tangibles to evaluate. It was found that whilst many metrics measure sustainability, many indices were not independent and did not provide an objective measure; and very few actually translated their efforts into a standard metric. In general, traditional patterns of industrial and economic activities are no longer viable. Thus, one of the challenges of sustainability in engineering research lies in linking measures of ecosystem functioning to engineering operations.

10.5 Limitations of measures of sustainability

Whilst the world governments attempt to set targets and policies for the next decade and century, this dissertation looked at what engineers can do today to contribute towards the change. To escape the rhetoric we have viewed the discussion from both macro and micro levels, the truth lies between the two extremes the deniers and phonetics. This discussion like many others currently being discussed have been natural triggers for the profession, as the centre of gravity is shifting towards sustainability in engineering. Failing to drive development towards a net positive outcome or change to sustainable engineering practices risks consigning a future of a irreconcilable path. The main critique of composite indicators is uncertainty in the variables used that it provides a subject summary based on judgment of weights or rankings

> "We should acknowledge at the outset the limitations of quantitative measures and that any measures are merely the map, not the territory Even though we cannot define sustainability objectively and unambiguously, we should not abandon or defer attempts to measure it. But we must be on our guard to keep well clear of thresholds. International trading in sustainability units could mean we all arrive at global survival (not sustainability) together" (Fricker,

[2] Note that sustainability principles should remain constant over time, whereas the choice of criteria and indicators may change rapidly as knowledge advances.

1998). “any competent statistician knows that "just collecting numbers" leads to nonsense”(Funtowicz and Ravetz, 1990)

A wide variety of tools, techniques and methodologies have been developed. These vary greatly in complexity, methodology, scope and application. As such there is no single tool that is universally used(Pelly et al., 2007).

10.6 Further research

The approach taken in characterising sustainability in engineering, a dynamic topic such as in the current study, has been primarily a qualitative one. I have begun to mine a number traits or characterizations of the subjects and hence support the existence of a variety of philosophies within practicing engineers. The criteria assessment questionnaire including indicators representing economic, environmental, social, and technological characteristics of engineering projects was formed within the consensus of literature including the most prominent philosophy and driving forces and optimised with the interview process but yet it was created under the same static input parameters. Although some qualitative analysis has been attempted, there needs to be evidence of patterns when parameters are varied. However, a more appropriate technique, given the stochastic nature of the assessment would be to identify important parameters and consider each of these statistically, quantifying the mean and variance. This approach would enable better modelling. Future work would benefit from identifying the dominant indicators that exist in the variations of engineering and technology characteristics. Finally, it is recommended that other limiting factors be incorporated into the questionnaire to enable a more realistic analysis of the scheme. As this study has been primarily quantitative, considering the relative parameters with a number of qualitative variations, it is necessary to calibrate the questionnaire to give a hierarchy or weighted average to the most significant parameter sets.

The development of key sustainability indicators contributes to operational sustainability, bridging the gap between the current methodologies and estimation tools. If sustainability in engineering is to be achieved, it has to adopt more long-term sustainable strategies at the feasibility stage of a development to promote environmental protection and conservation. These strategies must focus on continual improvement, through consideration in the decision process, therefore, the engineering industry and professionals’ alike need to consider a wide ranging issues in operations also known as spheres of influence.

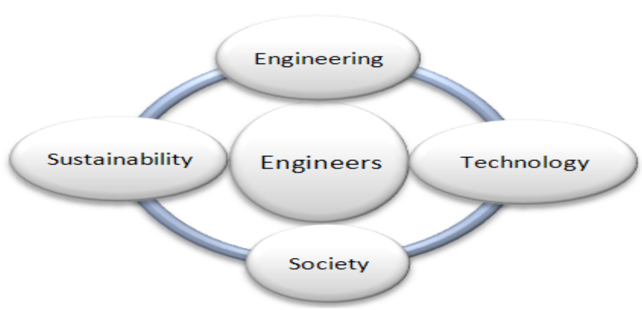

Figure 10-3: Spheres of influence

“sustainability requires not just new tools but also a new role” (Clift, 2006).

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Appendix A-Serial Search

Academic journals periodicals and newsletters featuring sustainable sustainability in tittle

	Journal title	Publisher	Year
1.	Agronomy for Sustainable Development	EDP Sciences	2005
2.	Agronomy for Sustainable Development: sciences des productions vegetales et de l'environnement	E D P Sciences	1981
3.	Alberta. Ministry of Sustainable Resource Development. Annual Report	Alberta. Ministry of Sustainable Resource Development	1996
4.	Biological Conservation, Restoration and Sustainability	Cambridge University Press	1999
5.	British Columbia. Legislative Assembly. Special Committee on Sustainable Aquaculture. Report of Proceedings (Hansard)	Legislative Assembly of British Columbia, Special Committee on Sustainable Aquaculture	2005
6.	Canadian Environmental Sustainability Indicators. Air Quality Indicator	Environment Canada	2005
7.	Canadian Environmental Sustainability Indicators. Freshwater Quality Indicator	Environment Canada	2005
8.	Canadian Environmental Sustainability Indicators. Greenhouse Gas Emissions	Environment Canada	2005
9.	Canadian Heritage. Sustainable Development Strategy	Canadian Heritage	2003
10.	ChemSusChem: Sustainable Chemistry Journal	Wiley-VCH	2008
11.	Commissioner for Environmental Sustainability Annual Report	Victorian government	2004
12.	Commissioner of the Environment and Sustainable Development to the House of Commons	UK government	1997
13.	Copper (Year) Volume II: Health, Environment and Sustainable Development	Canadian Institute of Mining, Metallurgy and Petroleum	1995
14.	CSA Sustainability Science Abstracts	CSA-proquest	2005
15.	Energy and Sustainable Development Magazine	Editions de l'Electricite et du Developpement Durable (2 e 2 d)	2004
16.	Energy for Sustainable Development	International Energy Initiative	1994
17.	Energy Resource and Environmental Sustainable Management	Ten Alps Publishing	1996
18.	Energy Sustainable Development: the journal of the international energy initiative	International Energy Initiative	1994
19.	Engineering Sustainability, Proceedings of the Institution of Civil Engineers	Thomas Telford.	2003
20.	Environment Canada's Sustainable Development Strategy	Environment Canada	2000
21.	Environment, Development and Sustainability: a multidisciplinary approach to the theory and practice of sustainable development	Springer Netherlands	1999
22.	Environment: Science and Policy for Sustainable Development	Heldref Publications	
23.	Environmentally Sustainable Development Proceedings Series	World Bank Group	1994
24.	Ethiopian Journal of Technology, Education and Sustainable Development	Bahir Dar University	2005
25.	European Directory of Sustainable and Energy Efficient Building - Components Services Materials	Earthscan / James & James	1993
26.	Forum for the Future. Sustainable Economy Programme. Policy Briefing	Forum for the Future	
27.	Health Canada. Sustainable Development Strategy	Health Canada	2000
28.	International Institute for Environment and Development. Sustainable Agriculture Programme. Gatekeeper Series	International Institute for Environment and Development	1987
29.	International Institute for Environment and Development. Sustainable Agriculture Programme. Hidden Harvest Research Series.	International Institute for Environment and Development	1993

30.	International Journal of Agricultural Sustainability	James & James/Earthscan	2003
31.	International Journal of Applied Sustainable Development	International Management Journals	2004
32.	International Journal of Arab Culture, Management and Sustainable Development	Inderscience	2008
33.	International Journal of Environment and Sustainable Development	Inderscience	2002
34.	International Journal of Environmental, Cultural, Economic& Social Sustainability	Common ground	2004
35.	international Journal of Innovation and Sustainable Development (IJISD)	Inderscience	2005
36.	International Journal of Low Energy and Sustainable Buildings	Kungliga Tekniska Hoegskolan	1999
37.	International Journal of Management and Sustainable Development	Inderscience	2005
38.	International Journal of Sustainability in Higher Education	Emerald	2000
39.	International Journal of Sustainable Design	Inderscience	2007
40.	International Journal of Sustainable Development	Inderscience	1998
41.	International Journal of Sustainable Development and Planning: encouraging the unified approach to achieve sustainability	W I T Press	2005
42.	International Journal of Sustainable Development and World Ecology	Sapiens Publishing	1994
43.	International Journal of Sustainable Energy	Taylor and Francis Group.	2003
44.	International Journal of Sustainable Engineering	Taylor & Francis Ltd.	2008
45.	International Journal of Sustainable Manufacturing	Inderscience	2007
46.	International Journal of Sustainable Manufacturing (IJSM)	Inderscience	2007
47.	International Journal of Sustainable Strategic Management	Inderscience	2007
48.	International Journal of Sustainable Transportation	Taylor & Francis Ltd.	2007
49.	International Journal of Technology Management & Sustainable Development	Intellect Ltd.	2002
50.	Journal "Chemistry for Sustainable Development	Russian Academy of Sciences	2000
51.	Journal of Asia Entrepreneurship and Sustainability	proquest	2005
52.	Journal of Education for Sustainable Development	Sage Publications India Pvt. Ltd.	2007
53.	Journal of Engineering for Sustainable Development: Energy, Environment, and Health	College publishing	2006
54.	Journal of Nature Science and Sustainable Technology	Nova Science Publishers, Inc.	2006
55.	Journal of Strategic Innovation and Sustainability		1999
56.	Journal of Sustainability Science and Management	Terengganu University Malaysia	2006
57.	Journal of Sustainable Agriculture	Haworth Press Inc and Japan Science and Technology Information Aggregator	1990
58.	Journal of Sustainable Agriculture: innovations for the long-term and lasting maintenance and enhancement of agricultural resources, production and environmental quality	Haworth Food & Agricultural Products Press	1990
59.	Journal of Sustainable Development	Canadian Center of Science and Education	2008
60.	Journal of Sustainable Development in Africa	Kalamazoo College. Fayetteville State University	1999
61.	Journal of Sustainable Forestry	Haworth Press Inc.	1993
62.	Journal of Sustainable Tourism	Multilingual Matters and Channel View Publications	1993
63.	Living Sustainably	Department of Environment and Conservation, Sustainability Programs Division	2005

64.	Local Environment: The Int. Journal of Justice and Sustainability	Routledge Taylor & Francis	1996
65.	Made in Holland. Sustainable Health Care	Ministerie van Economische Zaken, Economische Voorlichtingsdienst (EVD)	2004
66.	OECD and Environment and Sustainable Development	OECD Publications	1997
67.	Our Sustainable Future	University of Nebraska Press	
68.	Passive Solar Journal: Heating, Cooling, Hybrid Technologies and Strategies for Sustainable Design	American Solar Energy Society, Inc.	1982
69.	Proceedings of the National Academies: Sustainability Science	The National Academies USA,	2007
70.	Profitable Farms, Sustainable Systems, Healthy Landscapes Project Update	Murrumbidgee Catchment Management Authority	2006
71.	Public Health Agency of Canada. Sustainable Development Strategy	Public Health Agency of Canada	2007
72.	Public Works and Government Services Canada. Sustainable Development Strategy	Public Works and Government Services Canada	1997
73.	Renewable & Sustainable Energy Reviews	Elsevier Science	1997
74.	Renewable Energy World	PennWell Corporation	1996
75.	SA Water. Sustainability Report	South Australian Water Corporation	2003
76.	Science and Technology for Sustainable Development. 5NR Biennial Report	Environment Canada	1996
77.	Source O E C D. Environment & Sustainable Development	Organisation for Economic Cooperation and Development (O E C D)	1997
78.	Sustainability journal :Swedish Research for Sustainability	Formas , Swedish Research Council	1994
79.	Sustainability Report	Hydro-Quebec	1995
80.	Sustainability Science	Springer Tokyo	2006
81.	Sustainability, Economics, and Natural Resources	Springer	2005
82.	Sustainability: Science, Practice, and Policy	NBII and CSA	2005
83.	Sustainability: The Journal of Record	AASHE:Mary Ann Liebert, Inc.	2008
84.	Sustainable Building	Newzeye Ltd.	2006
85.	Sustainable Business Investor - America	Euromoney Institutional Investor Plc.	2000
86.	Sustainable Development	John Wiley & Sons Ltd.	1993
87.	Sustainable Development Digest	C D Publications, Inc.	2007
88.	Sustainable Development Law & Policy	American University, Washington College of Law	2001
89.	Sustainable Development Strategy	Indian and Northern Affairs Canada	1997
90.	Sustainable Development U K	Partnership Media Group Ltd.	1997
91.	Sustainable Development: Journal	John Wiley & Sons,	1993
92.	Sustainable Fisheries Livelihoods Programme Newsletter	Food and Agriculture Organization of the United Nations (F A O)	2000
93.	Sustainable Forest Management Network. Projects and Publications Guide	Sustainable Forest Management network	2001
94.	Sustainable Grazing on Saline Lands Network News	Australia, Land & Water Australia, Sustainable Grazing on Saline Lands	2004
95.	Sustainable Humanosphere	Kyoto University	2005
96.	Sustainable Industries Journal	Celilo Group Media	2003

97.	Sustainable Land Use Change in the Northwest Provinces of China. Research Reports	Australian National University, Asia Pacific School of Economics and Government	2004
98.	Sustainable Urban Areas	Delft University Press	2004
99.	Sustainable World Series, The	WIT Press	2002
100.	Sustaining Regions	Australian and New Zealand Regional Science Association Inc.	2001
101.	Systems Approaches for Sustainable Agricultural Development	Springer Netherlands	1992
102.	The International Journal of Sustainable Development and World Ecology	Sapiens	1995
103.	The Journal of Sustainable Product Design	Springer	2001
104.	The Journal of Sustainable Product Design: balancing economic, environmental, ethical and social issues in product design and development	Springer Netherlands	1997
105.	The McGill International Journal of Sustainable Development Law and Policy	McGill University, Faculty of Law	2005
106.	The Sustainable Times	Sustainable Times	1993
107.	The Sustainable World	W I T Press	2002
108.	Transport Canada. Entry Sustainable Development Strategy	Transport Canada	1997
109.	virtual Journal of Environmental Sustainability	Elsevier	2003
110.	Western Economic Diversification Canada. Sustainable Development Strategy	Western economic diversification canda	1997
111.	What Works: An Annotated Bibliography of Case Studies of Sustainable Development	California Institute of Public Affairs	1993
112.	World Journal of Sustainable Development	Isis Press	2006
113.	World Review of Entrepreneurship, Management and Sustainable Development (WREMSD)	Inderscience	2005
114.	World Review of Entrepreneurship, Management and Sustainable Development	Inderscience Publishers	2004
115.	World Review of Entrepreneurship, Management and Sustainable Development	Inderscience Publishers	2005
116.	World Review of Science, Technology and Sustainable Development	Inderscience	2004
117.	World Watch: working for a sustainable future	Worldwatch Institute	1988

Appendix B-Sustainability definitions

	Author	Synopsis	D
1	(Hicks, 1972)	The amount one can consume during a period and still be as well off at the end of the period.	
2	(Holling, 1973)	multiscale, dynamic, hierarchical measure of resilience, vigour and organization. Resilience is the ability of ecosystems to persist despite external shocks, i.e., the amount of disruption that will cause an ecosystem to switch from one system state to another	S
3	(Coomer, 1979)	sustainable society is one that lives within the self-perpetuating limits of its environment. That society...is not a 'no-growth' society. It is, rather, a society that recognizes the limits of growth and looks for alternative ways of growing	
4	(Allen, 1980)	Sustainable utilization is a simple idea: we should utilize species and ecosystems at levels and in ways that allow them to go on renewing themselves for all practical purposes indefinitely	
5	(Ruckelshaus, 1989)	Sustainability is the emerging doctrine that economic growth and development must take place, and be maintained over time, within the limits set by ecology in the broadest sense - by the interrelations of human beings and their works, the biosphere and the physical and chemical laws that govern it. It follows that environmental protection and economic development are complementary rather than antagonistic processes	
6	(Tietenberg, 1984)	The sustainability criterion suggests that, at a minimum, future generations should be left no worse off than current generations.	S
7	(Repetto, 1985)	The core of the idea of sustainability, then, is the concept that current decisions should not impair the prospects for maintaining or improving future living standards. ... This implies that our economic systems should be managed so that we live off the dividend of our resources, maintaining and improving the asset base. This principle also has much in common with the ideal concept of income that accountants seek to determine: the greatest amount that can be consumed in the current period without reducing prospects for consumption in the future	E
8	Repetto	The core of the idea of sustainability, then, is the concept that current decisions should not impair the prospects for maintaining or improving future living standards....This implies that our economic systems should be managed so that we live off the dividend of our resources, maintaining and improving the asset base. This does not mean that sustainable the current stock of natural resources or any particular mix of human, physical, and natural assets development demands the preservation of	T
9	(Burness and Cummings, 1986)	in a pedagogical sense sustainability requires that all processes operate only at their steady state, renewable level, which might then suggest a return to a regulated caveman culture	T
10	(Richard et al., 1986)	Since increased human populations will cause demands for food to continue to grow in the foreseeable future, sustainability means three different definitions sustainability as food sufficiency; sustainability as stewardship; and sustainability as continuity.	
11	(Daly, 1986)	Sustainability, like justice, is a value not achievable by purely individualistic market processes	S
12	(Pearce, 1987)	The sustainability criterion requires that the conditions necessary for equal access to the resource base be met for each generation	T
13	(Goodland and Ledec, 1987)	sustainable development implies using renewable natural resources in a manner which does not eliminate or degrade them, or otherwise diminish their usefulness for future generations	

	Author	Synopsis	D
14	(Brown et al., 1987)	one in which humans can survive without jeopardizing the continued survival of future generations of humans in a healthy environment	
15	(Bruntland, 1987)	Meeting the needs of the present without compromising the ability of future generations to meet their own needs.	S
16	(Pearce, 1988)	Equally self-evident is the implicit assumption that sustainability is a 'good thing' - that is optimizing within sustainable use rates is a desirable objective. On these terms, sustainability could imply use of environmental services over very long time periods and, in theory, indefinitely.	E
17	(Turner, 1988b)	Conservation Strategy gave considerable prominence to the sustainability Concept, although it's precise meaning and practical applications were not presented in a detailed and operational form.	N
18	(Liverman et al., 1988)	We developed our own simple, anthropocentric working definition by which we mean sustainability to be the indefinite survival of the human species (with a quality of life beyond mere biological survival) through the maintenance of basic life support systems (air, water, land, biota) and the existence of infrastructure and institutions which distribute and protect the components of these systems	N
19	(O'Riordan, 1988)	Sustainability is a much broader phenomenon (than sustainable development), embracing ethical norms pertaining to the survival of living matter, to the rights of future generations and to institutions responsible for ensuring that such rights are fully taken into account in policies and actions.	S
20	(Markandya and Pearce, 1988)	The basic idea (of sustainability) is simple in the context of natural resources (excluding exhaustibles) and environments: the use made of these inputs to the development process should be sustainable through time. ....If we now apply the idea to resources, sustainability ought to mean that a given stock of resources - trees, soil quality, water and so on - should not decline.	N
21	(Turner, 1988a)	In principle, such an optimal (sustainable growth) policy would seek to maintain an 'acceptable' rate of growth in per-capita real incomes without depleting the national capital asset stock or the natural environmental asset stock. It makes no sense to talk about the sustainable use of a non-renewable resource (even with substantial recycling effort and reuse rates). Any positive rate of exploitation will eventually lead to exhaustion of the finite stock	E
22	(Jeroen et al., 1998)	Environmental sustainability is defined as maintenance of life-support systems, economics sustainability is the economic tantamount of environmental sustainability, being defined as maintenance of economic capital. This definition of economic sustainability falls back on the Hicksian definition of income (Hicks, 1946): the maximum amount of income that can be spent without reducing real consumption in the future. Social sustainability is defined as maintenance of social capital	E
23	(Conway and Barbier, 1988)	The common use of the word "sustainable" suggests an ability to maintain some activity in the face of stress -- for example to sustain physical exercise, such as jogging or doing push-ups -- and this seems to us also the most technically applicable meaning. We thus define agricultural sustainability as the ability to maintain productivity, whether of a field or farm or nation, in the face of stress or shock	T
24	(Manning, 1990)	Sustainability may be just an elusive philosophical aspiration like happiness' or justice.	S
25	(Daly, 1991)	the 'physical conditions sustainability of the society's material and energy throughputs' (1) It's rates of use of renewable resources do not exceed their rates of regeneration (2) It's rates of use of non renewable resources do not exceed the rate at which sustainable renewable substitutes are developed (3) It's rates of pollution emission do not exceed the assimilative capacity of the environment.	

	Author	Synopsis	D
26	(Robert, 1991)	A transition to sustainability involves moving from linear to cyclical processes and technologies. The only processes we can rely on indefinitely are cyclical, all linear processes must eventually come to an end	
28	(Dower et al., 1992)	In order for a course of action to be sustainable it should be compatible with the local culture by respecting the structure of the society and values of the people.	
27	(Meadows et al., 1992)	A sustainable society is one that can persist over generations, one that is far-seeing enough, flexible enough, and wise enough not to undermine either its physical or its social systems of support."	
28	(Norton, 1992)	Sustainability is a relationship between dynamic human economic systems and larger, dynamic, but normally slower-changing ecological systems, such that human life can continue indefinitely, human individuals can flourish, and human cultures can develop--but also a relationship in which the effects of human activities remain within bounds so as not to destroy the health and integrity of self-organizing systems that provide the environmental context for these activities	S
29	(Solow, 1993)	Sustainability is a vague concept. It is intrinsically inexact. It is not something that can be measured out in coffee spoons. It is not something that you could be numerically accurate about you are almost forced logically to think about equity not between periods of time but equity right now It is an obligation to conduct ourselves so that we leave to the future the option or the capacity to be as well off as we are. It is not clear to me that one can be more precise than that. Sustainability is an injunction not to satisfy ourselves by impoverishing our successors...There is no specific object that the goal of sustainability, the obligation of sustainability, requires that we leave untouched	S
30	(Pearce and Atkinson, 1993)	Sustainable economic development is continuously rising, or at least non-declining, consumption per capita, or GNP, or whatever the agreed indicator of development is.	
31	(Hawken, 1993)	Sustainable businesses: Replace nationally and internationally produced items with products created locally and regionally. Take responsibility for the effects they have on the natural world. Do not require exotic sources of capital in order to develop and grow. Engage in production processes that are human, worthy, dignified, and intrinsically satisfying. Create objects of durability and long-term utility whose ultimate use or disposition will not be harmful to future generations. Change consumers to customers through education	E
32	(Beder, 1993a)	Cooption of Language: Sustainable development represents a cooption of the term sustainability which once represented ideas of stability and equilibrium and harmony with nature. In the late 1960s and early 1970s the term was used in the context of the limits to growth debate as part of the argument against economic and population growth. For example the editors of the magazine The Ecologist argued that economic growth could not continue on into the future without disaster: The principal defect of the industrial way of life with its ethos of expansion is that it is not sustainable... By now it should be clear that the main problems of the environment do not arise from temporary and accidental malfunctions of existing economic and social systems. On the contrary, they are the warning signs of a profound incompatibility between deeply rooted beliefs in continuous growth and the dawning recognition of the earth as a space ship, limited in its resources and vulnerable to thoughtless mishandling.	
33	(DuBose, 1994)	While other attributes such as colour or temperature can be ascribed to isolated objects, this is not the case with sustainability. It is somewhat of a misnomer to say that a technology in and of itself is sustainable. This is	T

	Author	Synopsis	D
		not to say that therefore nothing is sustainable or that sustainability can not occur -- it is simply that our way of speaking of sustainability is imprecise and misleading. Sustainability does not describe a quality that resides within the confines of an individual technology or practice but refers instead to the nature of the relationship between the technology and its context	
34	(DuBose, 1994)	No one element can by itself indicate sustainability; it is the nexus of relations between elements working in harmony that indicates sustainability -- like an equation for which an answer cannot be derived from one variable alone but requires the interaction of the variables for solution	S
35	(Costanza, 1994)	sustainability entails maintenance of (1) a sustainable scale of the economy relative to its ecological life support system; (2) a fair distribution of resources and opportunities between present and future generations, as well as between agents in the current generation, and (3) an efficient allocation of resources that adequately accounts for natural capital.	
36	(Liddle, 1994)	when one talks about sustainability, one is not talking about the conservation of any one thing, asset, or much less, industry. One is talking about the transformation of assets and opportunities, and how fair that transformation is both across generations and across people of the current generation. No one industry is essential to sustainability. Sustainability is concerned with the portfolio of assets and how that portfolio changes. The issue for an industry is how the sustainability paradigm creates challenges and new opportunities. How the industry adapts to this new social and environmental paradigm determines whether the industry sustains. The construction industry's fortunes are inextricably intertwined with both the environment and sustainability. The construction industry affects the environment in a number of ways: it consumes resources, contributes to waste, and, by its very nature, alters the environment. Also, the construction industry has a role in many of the important aspects of sustainability. It is or can be involved, for example, in the transformation of assets, reduction of wastes, and improvement of energy efficiency. Thus, a move toward the sustainability paradigm will have an impact on the construction industry, and how well the construction industry adapts to the new paradigm will affect the facility with which sustainability is achieved	T
37	(Coop, 1995)	Sustainable society - Society whose long term prospect for continuing to exist are good. Such a society would be characterized by an emphasis on preserving the environment, developing strong peaceful relationships between people and nations, and an emphasis on equitable distribution of wealth	S
38	(Starik and Rands, 1995)	sustainability is the ability of one or more entities, either individually or collectively, to exist and flourish (either unchanged or in evolved forms) for lengthy time-frames, in such a manner that the existence and flourishing of other collectivities of entities is permitted at related levels and in related systems.	
39	(Munasinghe and Shearer, 1995)	Biogeophysical sustainability is the maintenance and/or improvement of the integrity of the life-support system on Earth. Sustaining the biosphere with adequate provisions for maximizing future options includes providing for human economic and social improvement for current and future human generations within a framework of cultural diversity while: (a) making adequate provisions for the maintenance of biological diversity and (b) maintaining the biogeochemical integrity of the biosphere by conservation and proper use of its air, water and land resources. Achieving these goals requires planning and action at local, regional and global scales and specifying short- and long-term objectives	

	Author	Synopsis	D
		that allow for the transition to sustainability	
40	(Robert et al., 1997)	In order for society to be sustainable, nature's functions and diversity are not systematically subject to; increasing concentrations of resources substances extracted from the Earth's crust, increasing concentrations of substances produced by society, impoverished by physical displacement over-harvesting or other forms of ecosystem manipulation And Resources are used fairly and efficiently in order to meet human needs globally.	
41	(Ikerd, 1997a)	Sustainability is the broadest, most inclusive concept of environmental stewardship.	S
42	(Lachman, 1997)	"The focus and scale of sustainability efforts depend on local conditions, including resources, politics, individual actions, and the unique features of the community. The sustainable communities approach has been applied to issues as varied as urban sprawl, inner-city and brownfield redevelopment, economic development and growth, ecosystem management, agriculture, biodiversity, green buildings, energy conservation, watershed management, and pollution prevention. Many of these issues and other community problems cannot easily be addressed by traditional approaches or traditional elements within our society. Many people feel it is better to address such problems through a more collaborative and holistic systems approach because such problems are diffuse, multidisciplinary, multiagency, multistakeholder and multisector in nature	
43	(Marcuse, 1998)	sustainability is not a goal; it is a constraint on the achievement of other goals	
44	(Fricker, 1998)	Human nature being what it is, we may push the global physical and biological capacities to their very limits, which will be survival rather than sustainability. Survival is merely not dying, whereas we probably think of sustainability in terms of justice, interdependence, sufficiency, choice and above all (if we were to think deeply about it) the meaning of life. Sustainability, therefore, is also about the non-material side of life—the intuitive, the emotional, the creative and the spiritual	
45	(Cary, 1998)	Sustainability is not a fixed ideal, but an evolutionary process of improving the management of systems, through improved understanding and knowledge. Analogous to Darwin's species evolution, the process is non-deterministic with the end point not known in advance	
46	(Sachs, 1999)	Distinguishes between partial sustainability and whole sustainability. To realise whole sustainability, the following criteria (related to the three dimensions plus a fourth dimension focusing on political systems) should be met simultaneously	
48	(Peacock, 1999)	sustainability is purely a matter of the management of scarce and ever-diminishing "negentropy",	S
49	(Pearce, 1999)	Sustainability is a system state in which no internal (intra-system) or external (extra-system) constraints are violated that would threaten the stability of the system into the foreseeable future. Given this definition, a sustainable system is one in which the following constraints are met: 1) stakeholder satisfaction-basic needs met; 2) Resource base impact-no or neutral impacts; 3) Ecosystem impact-no or neutral impacts.	S
50	(Oskamp, 2000)	Sustainability may be defined as using the world's resources in ways that will allow human beings to continue to exist on Earth with an adequate quality of life	T
51	(Dorf, 2001)	Living within a frame work of earths system, both thermodynamically and kinetically to maintain change.	S
52	(Gibson, 2001)	Sustainability demands the protection of resources and ecological integrity over the long term, combined with great improvements in	

	Author	Synopsis	D
		human well-being, especially among the poor	
53	(Harris and Goodwin, 2001)	The concept of sustainability derives from a shift in perspective—from a focus on economic development that is often defined as the expansion of consumption and GNP to a new view of development called sustainable development	
54	(Parris and Kates, 2003)	There are those who maintain that sustainable development is better defined in the form of normative judgments, such as goals and targets coded in formal agreements, treaties, and declarations, not in the form of semantic or philosophical clarification	
55	(Johnston, 2003a)	is as an ideal state of long-term social, economic and ecological stability, a target towards which we strive, rather than one we expect to reach	
56	(Lebel, 2005)	The relations between nodes in production consumption systems are shaped not only by economics and material flows, but also by culture, values, and power. Transitions to sustainability will need to harness all three.	
57	(ESI, 2005)	Sustainability is a characteristic of dynamic systems that maintain themselves over time; it is not a fixed endpoint that can be defined.	S
58	(Hargroves and Smith, 2005)	Progress that improves economic social and environmental well being with no major tradeoffs locally and globally ,now and in the future	S
59	(Kajikawa et al., 2007)	Sustainability is lexically defined as the ability to maintain something undiminished over some time period	
60	(Australian Government, 2007)	using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.	

Appendix C-Survey Questionnaire

DEMOGRAPHIC

1. Gender of respondent
o1.00, male   o 2.00, female   o9.00 neither

2. What is your marital status?
o1.00, single   o 2.00, married   o9.00 neither

3. What is the highest level of qualification attained?
o1.00, PhD   o 2.00, ME   o 3.00,BE
o4.00,MS   o5.00, BS   o6.00,MA
o7.00, Trade   o 8.00, Tafe   o9.00 , High school

4. Do you consider yourself an expert?
o 1.00 yes   o 2 no   o 3 other

5. Which of the following best describes your industry?
o1.00 manufacturing   o 2.00 HSE   o3.00 Design
o4.00 construction   o 5.00 maintenance   o 6.00 production

6. You area of employment in an Engineering
o1.00, Administration   o 2.00, management   o3.00,technical   o4.00, other

7. Please indicate the area of specialization
o1.00, environmental   o 2.00, chemical   o3.00, electrical
o4.00, mechanical,   o5.00, process   o 6.00, civil

8. How old are you?

9. How many years have you practiced engineering (experience)?

PERSONAL UNDERSTANDING OF SUSTAINABILITY
Out of a scale of 1 to 5

10. State your familiarity with the Burtland report and its definition of Sustainability?
o 1.00, not familiar   o 2.00, Low familiarity   o3.00, Medium familiarity
o4.00, Highly familiar   o5.00, very familiar

11. rate the implementation of sustainability in participant's organization
o 1.00, No sign   o 2.00, Have not started   o3.00, Just started
o4.00, Highly noticeable   o5.00, Extremely noticeable

12. what is the importance of sustainability policy in participant's organization?
o 1.00, Not important   o 2.00, Low importance   o3.00, Medium importance
o4.00, Highly important   o5.00, Very important

13. what is the importance of sustainability to you personally
o 1.00, Not important   o 2.00, Low importance   o3.00, Medium importance
o4.00, Highly important   o5.00, Very important

IMPORTANCE RANKING OF SUSTAINABILITY CRITERIA

Out of a scale of 1 to 5

- 1 not important to the concept of Sustainability
- 2 low importance to the concept of Sustainability
- 3 medium importance to the concept of Sustainability
- 4 high importance to the concept of Sustainability
- 5 critically important to the concept Sustainability

Using your experience/opinion please assign relative levels of Sustainability importance by allocating points between 1 (least important) and 5 (most important)

Factor	Name	Explanations
1.	Resource availability	Reliability of resources guards against supply disruptions, Freshwater consumption
2.	Quality of Life	Access to air, water, land resources ensuring adequate quality of life
3.	Energy efficiency	Material and energy intensity, Energy usage per person
4.	Employment	Promotion of opportunities for employment
5.	Work atmosphere	management accessibility, coworker relations
6.	Social acceptance	Community participation Social inclusion
7.	Health and Wellness	Protection of human safety & health , OHS occupational health and safety
8.	institutional	Industry regulations , Kyoto targets and CO2 emissions, Compliance with local and international laws
9.	Low entropy	Generate energy from renewable sources or waste
10.	environmental Manufacturing-	Encourage reuse and/or repair , recycling or use of recycled products, Re-use of process by-products as source of energy
11.	Adaptability	Early warning systems
12.	Stress at work	Work time (e.g., length, flexibility)
13.	Pollution control	Reduce/prevent Industrial Pollution
14.	Global warming	Climate change green-house gas emissions reduction
15.	Economic viability	Link local production with local consumption
16.	Affordability	Viability of the industry -minimizes costs to ensure competitiveness and has adequate funding to sustain operations
17.	Corporate responsibility	Accountability , Preservation of cultural values
18.	Inclusivity	social justice, community development Encourage local action and decision making
19.	Waste hazards	Waste management and minimization
20.	Ethics	Codes of conduct, professional ethic, spirituality
21.	Carrying capacity	ecological loading Reduce waste and/or maximize resource use
22.	Training	Specialized engineering training, educational Opportunity for learning and career advancement , tuition reimbursement, on-site training
23.	Performance of the system	Reliability and Durability
24.	Collaboration	Public awareness and information, Needs and basic rights
25.	Ozone Layer Depletion	Consumption of Ozone Depleting Substances
26.	Integration	Integrated management seeks to combine the social, economic, environmental and technology
27.	Technology end use	Consumption of Ozone Depleting Substances
28.	Intergenerational Equity	Transparency in practice and process
29.	Time scale- Design life cycle	Conceptual Design, Detailed Design, Construction, Start-Up/ Comm-issioning, Operations/Maintenance, Phase-Out/ Decommissioning
30.	organizations	Organization's approach to addressing employees' health and safety, economic, social and other needs
31.	Design intentions	Design for disassembly , Decommissioning
32.	involvement	Engineers involvement in decision-making (e.g., meetings to discuss key issues, system for suggestions)

DESCRIPTIVE OPEN-ENDED PERCEPTION QUESTIONS

Interview Question 1 asked: What is the status of sustainability in your engineering organisation, what are the characteristics or attributes? Is it a utopian state or pseudo ideal process? Is it a strategy? Is it real or an illusion?

Interview Question 2 asked: Sustainability as processes can it measured? What are the key indicators and criteria? What are its characteristics and challenges? What tangible information and contextual factors affect decision makers when making sustainability decisions and how do these affect decision outcomes?

Interview Question 3 asked: How do we improve the engineering design processes to include sustainability? Where do these complex issues leave us engineers and designers? How would engineers apply sustainability to preliminary designs?

Interview Question 4, asked: in your opinion what is the current state of sustainability definitions strengths and weaknesses?

Interview Question 5 and 6 asked: What level of sustainability assessment exists among engineering system? What is the state of sustainability capabilities in engineering?

Interview Question 7 asked: what is the engineering perspective on applied sustainability, most important attributes, how do we try to improve it? How strongly is the sustainability values embedded into engineering? To what extent do criteria satisfy the sustainability appraisal?

Appendix D- Ethics Approval

USQ
AUSTRALIA

The University of Southern Queensland

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GFE012

19 February 2008

Mr. Abdallah Hasna

Re: Sustainability Philosophy in Engineering Context Review and Discussion

Dear Abdallah

The USQ Human Research Ethics Committee recently reviewed your amended application for ethical clearance. Your project has been endorsed and full ethics approval was granted 013/02/08. Your approval reference number is: **H07STU713** and is valid until **13/02/09**.

The Committee is required to monitor research projects that have received ethics clearance to ensure their conduct is not jeopardising the rights and interests of those who agreed to participate. Accordingly, you are asked to forward a **written report** to this office after twelve months from the date of this approval or upon completion of the project.

A questionnaire will be sent to you requesting details that will include: the status of the project; a statement from you as principal investigator, that the project is in compliance with any special conditions stated as a condition of ethical approval; and confirming the security of the data collected and the conditions governing access to the data. The questionnaire, available on the web, can be forwarded with your written report.

Please note that you are responsible for notifying the Committee immediately of any matter that might affect the continued ethical acceptability of the proposed procedure.

Yours sincerely

Gillian Fulton
Postgraduate Students and Research Ethics Officer
Office of Research and Higher Degrees

Appendix E-Letter of information

Dear Sir / Madam (potential interviewee)

My name is Abdallah Hasna I am in the process of conducting my master's research in Engineering at the University of Southern Queensland under the supervision of Dr. Thorpe.

I am conducting a research study into concept of sustainability and the engineering discipline. It is hoped that this research will provide practice, policy, and procedural recommendations. One of the research objectives is to listen carefully to engineers; hence your feedback will assist in further development of this subject area. To investigate these issues, I am asking you to participate. Your opinions and feedback are extremely important since you are the ones who ultimately shape and mold the profession.

If you decide to volunteer, you are asked to complete a short online survey. The interview (questionnaire) should take no longer than approximately ten minutes to complete. There are no right or wrong answers, only your opinions and ideas. At the end of the survey, you will be provided an opportunity for feedback should you wishes to share some comments anonymously during the course of the interview; your wishes will be respected.

Your name and the name of the organization will not be used in publications; Information concerning the confidential and voluntary nature of this study is detailed on the Consent to Participate in Research webpage which is the initial page once you have cleared the password protection. However, essential highlights of the consent include:

- Participation in this study is voluntary.
- There are no known or anticipated risks from participating in this study.
- Any information that you provide will remain confidential.
- Declining to participate or withdrawing from the study will have no impact on you or your job in any way.
-The study has received ethical clearance from the University of Southern Queensland.

Findings from the interviews will form data to be analysed in the research write up and interviewees will be encouraged to discuss and consider potential ideas for improving the questionnaire.

Thank you,

Kind Regards
Abdallah Hasna

Appendix F- Consent Form

Your participation in the study is completely voluntary; you may be excused without any penalty or having to give reasons.

I volunteer to participate in this study.

Title

First Name

Surname

Name of projects I have worked on

Expertise

Email address

I understand that:

1. I may stop the interview at any time;
2. I may withdraw from the study at any point at which time I can direct the researcher to keep or destroy my information;
3. My name and the name of my organization will not be identified;
4. I may ask that some of my comments remain anonymous and that my organization and community remain anonymous as well;
5. Neither my organization nor I in person are obligated to participate in further research and
6. I have a right to ask questions about the project at any time.

I have a right to ask questions about the project at any time

- ☐ Click here if you agree
- ☐ Click here to terminate the interview

Appendix G- Interview Guide

Interview with experts Information sheet

This information sheet is used to obtain consent from participations in study it forms part of the pre-interview negotiations. As an introduction, I recite the following

1. Good morning/ afternoon, 'Hello', (introduce myself), my Name is Abdallah Hasna, I am a Master of Engineering Candidate at the University of Southern Queensland, Faculty of engineering and surveying.
2. I am conducting this study as part of my master research.
3. Your participation in the study is completely voluntary, you may decline (a softer word than refuse) to participate without penalty, without any penalty or having to give reasons. You have the freedom to participate - this is the principle of autonomy, a cornerstone of ethics.
4. The application has been approved by USQ ethics review committee.
5. This interview is being conducted to obtain your input about the discussion of sustainability in engineering, as a practising professional we ask for your participation to emphasize the perceived problems of criteria and indicators etc.
6. I am especially interested in any problems you have faced or are aware of and recommendations you may have."
7. We have approached you as potential research participant because you fit our selection criteria. These criteria are degree qualified, design engineer and currently employed in that capacity.
8. We would like you to answer a series of questions, during this interview question
9. The first set of questions are designed to collect information about the respondents i.e. affiliation, experience and area expertise.
10. The second set of questions is designed to collect information about interviews beliefs regarding sustainability.
11. The third set is importance ranking of criteria.
12. The final set of questions is designed provide a feedback
13. Each interview will require an average of 30 minutes to complete (range 25–30 minutes).
14. All interviews will conduct by a single interviewer between 1 March and 24 December 2007.
15. You confidentiality will be ensured, and explain what will be done if you find an abnormality. Take great care to reassure parents that no child will be forced to participate, even if a parent has given permission for participation. Remember that if children are able to understand what will be done, they must give assent as well. The parent should be the judge of the ability to understand.
16. Would you like further information; for example, here is the name and telephone number of a contact person Dr David Thorpe If you have any queries, more information may be obtained at telephone number (07) 34704532
17. Is there any other information or suggestions about this interview or otherwise that you think would be useful for me to know?