University of Pretoria

RESEARCH REPORT

The development of the Sustainable Technology Balance Sheet: a generic technology assessment tool to assess the sustainability of renewable energy technologies.

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A project report submitted in partial fulfilment of the requirements for the degree of

Master of Engineering (MEM)

in the

**GRADUATE SCHOOL OF TECHNOLOGY MANAGEMENT,
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND
INFORMATION TECHNOLOGY,
UNIVERSITY OF PRETORIA**

01 June 2010

Abstract

Solutions to sustainability problems may be achieved through the use of new technology that reduces wastes and provides development opportunities. The impacts of technologies have to be assessed in structured approaches to provide decision-makers with strategic information. Traditional technology assessment methods can be complex and highly resource intensive with long lead times; consequently, the applications of these methods are limited, especially in Africa. Where these methods have been applied, the conclusions that are generated are also not always effectively communicated, which leads to limited buy-in from stakeholders. A generic rapid technology assessment framework and implementation process is therefore proposed utilising a popular method that has been modified to include sustainability factors and a systems approach, while remaining simple and intuitive: the Sustainable Technology Balance Sheet. The method addresses technology assessment from a qualitative view by including sustainability criteria developed through stakeholder engagement and technical factors through expert opinion, while inducing a life cycle approach to ensure system awareness. The method was developed by engaging with a renewable energy case study, specifically in the rural-African context.

Keywords: Technology Assessment, Sustainability, Sustainable Development, Renewable Energy.

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List of Acronyms

AHP	Analytical Hierarchy Process
CTA	Constructive technology Assessment
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
EIA	Environmental Impact Assessment
EOI	Expression of Interest
FBOMS	The Brazilian Forum of NGOs and Social Movements
IAP	Invasive Alien Plant
IPCC	The Intergovernmental Panel on Climate Change
ITA	Innovative Technology Assessment
IRR	Internal Rate of Return
LCA	Life Cycle Analysis
MCDA	Multi Criteria Decision Analysis
MDG	Millennium Development Goals
NEMA	National Environmental Management Act
NFSD	National Framework on Sustainable Development
NPV	Net Present Value
NSF	National Science Foundation
OTA	Office of Technology Assessment
PIA	Privacy Impact Assessments
PPP	Public-Private Partnership
pTA	Participatory Technology Assessment
RA	Risk Assessment
R&D	Research and Development
RETs	Renewable Energy Technologies
SD	Sustainable Development
SIA	Social Impact Assessment
STBS	Sustainable Technology Balance Sheet
TA	Technology Assessment
TBS	Technology Balance Sheet
U.S.	United States
VAI	Value Added Industry
WCED	World Commission on Environment and Development
WfE	Working for Energy
WfW	Working for Water

1. Background

This chapter provides the basic understanding of energy requirements for sustainable development and the policies and drivers which are prevalent. Technology Assessment (TA) and its shortcomings are also addressed, as it relates to sustainability principals and sustainable development methodologies. The Renewable Energy Technologies (RETs) are discussed as a backdrop, ascertaining the impacts of RETs by focusing on life cycle creation and thinking. It also provides a better understanding about technology and sustainability and its existence in the present day. The chapter concludes with the research problem and objectives.

1.1. Introduction: the sustainable development problem

The Millennium Development Goals (MDGs) challenges the world to address key constraints to achieve these goals in a sustainable manner (Sanchez *et al*., 2007).
These goals can be aligned to the conditions required to achieve sustainable development as described by The World Commission on Environment and Development (WCED, 1987), as indicated below, to better understand the scope and nature of these challenges:

- economic growth that is significantly greater than population growth;
- population size and growth that are in harmony with the changing productive potential of the eco-system;
- changes in the exploitation of resources, direction of investments, orientation of technological development and institutions that are consistent with future as well as present needs; and
- equitable access to resources so as to enable social growth.

Energy is earmarked as a key resource consideration as it is closely linked to the sustainable development paradigm. The impact of energy technologies can include climate change, which is associated with excess use of energy, and poverty, due to a lack of access to energy. Solutions to these sustainability problems may be achieved by using new technologies, such as RETs, that reduces pollution and, in some instances, provides development opportunities. Such solutions can, however, only be achieved if the correct technology strategies are followed by effectively assessing and communicating viable options to policy makers (IPCC, 2007).

One of the key areas which need to be addressed for sustainable development are the questions surrounding energy, the energy demands levied by sustainable development as well as the various implications from its extraction, generation and use should be evaluated. As the worldwide demand for energy resources increase, so too does the diverse range of impacts occurring during the entire project life cycle and energy value chain relating to the various acquisition and operational activities as well as from the utilised technologies.

In attempting to address the sustainable development challenges which technology presents, structured approaches and firm methodologies need to be developed and implemented as a prerequisite to ensure the comprehension and coordination to reach intended outcomes. TA can provide the basis for this development (Bossel, 1999).

Although scientific and technological knowledge is largely proclaimed as an important factor for sustainability, it is still not recognised in practice as a decisive factor (Sikdar *et al*, 2004). Sustainability in particular is inadequately addressed in technology assessments (Musango and Brent, 2010).

The global uptake of the sustainable development concept and the 2002 Johannesburg World Summit on Sustainable Development has lead to various policy initiatives specifically in South Africa, including the Department of Environmental Affairs and Tourism (DEAT) National Framework on Sustainable Development (NFSD) that was published in 2008. Figure 1.1 shows the four major sustainability sectors or holons, these are the areas which contain factors which influence sustainability. These include the economy which is encapsulated by the socio-political systems in which we interact, which in turn occurs within the common environment consisting of the ecosystem services on which we all depend for survival. These are subsequently supported by a foundation factor of governance to which must be adhered. All of the holons interact and influence the others thus creating sustainable linkages. Technology is not viewed as an intrinsic concern.

In National Environmental Management Act (NEMA) it states that development must be socially, environmentally and economically sustainable. In the Act, 'best practicable environmental option' means the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as in the short term (van der Linde, 2008).

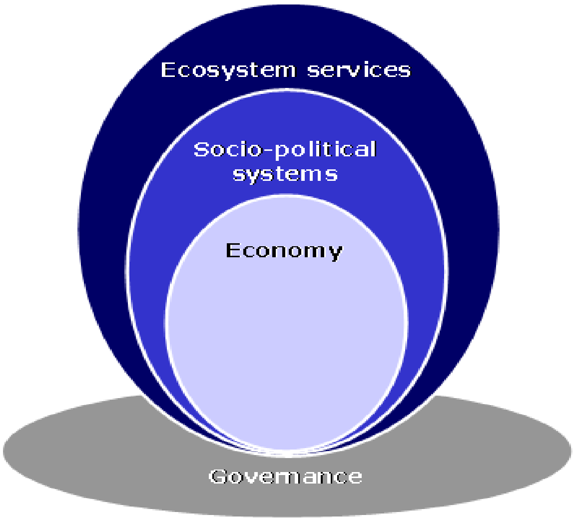

Fig. 1.1: Source: Adapted from National Framework for Sustainable Development (NFSD), 2008

Technology must however be seen as a key factor for sustainable development, as it imparts the skills and knowledge from which humans take environmental resources and transform them into meaningful objects, which satisfies our demands (Sikdar *et al*., 2004). Science and technology thus provides us with the methodologies to create the tools required to meet challenges such as energy and to coordinate these to achieve sustainable development

One of the great parodies caused by technology, which seek to solve the problems of living, within limits, is that they often create the very situations they are intended to relieve (de Gregoti, 1985). This double-edged nature of technology can be clearly illustrated by technology as potential creator of money and jobs and potential destroyer of ecosystems and culture; these traits are particularly relevant to industry (Janes, 1996).

Making use of the original National Framework on Sustainable Development as shown above many experts have proposed modified versions (Brent & Pretorius, 2008) which better encapsulates and communicates the importance which technology has on the sustainability of a system. The modified framework places a technology Holon at the heart of the sustainability spheres with its effects radiating into each of the traditional sustainability spheres (Figure 1.2.). This indicates a paradigm shift, placing technology into the mainstream of sustainability thinking and providing better awareness towards the critical nature of technology assessment for sustainable development.

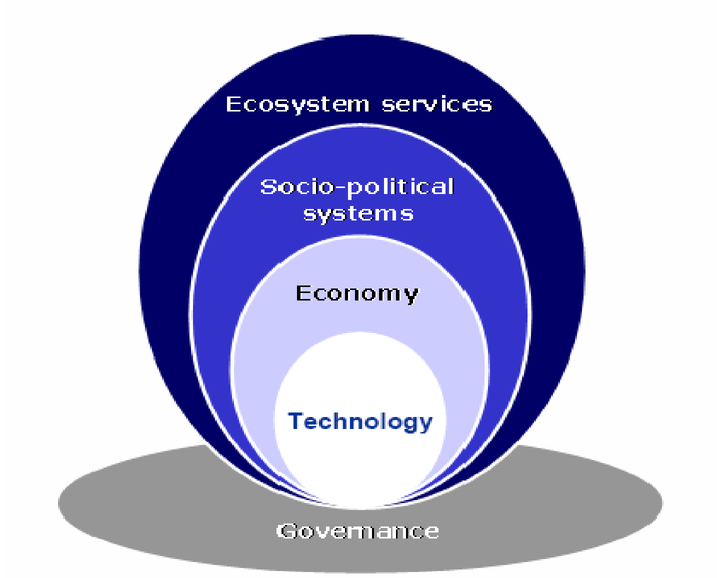

Fig. 1.2: Source: Adapted from National Framework for Sustainable Development (NFSD), 2008

This thinking must be augmented by the cognitive realisation of the underlying drivers towards sustainability, which proliferate as different forces experienced by a system.

A very good representation of the drivers of sustainable development is shown in Figure 1.3.

These drivers become very apparent within Technology Assessment methodologies and form the cornerstone of the proposed logical frameworks.

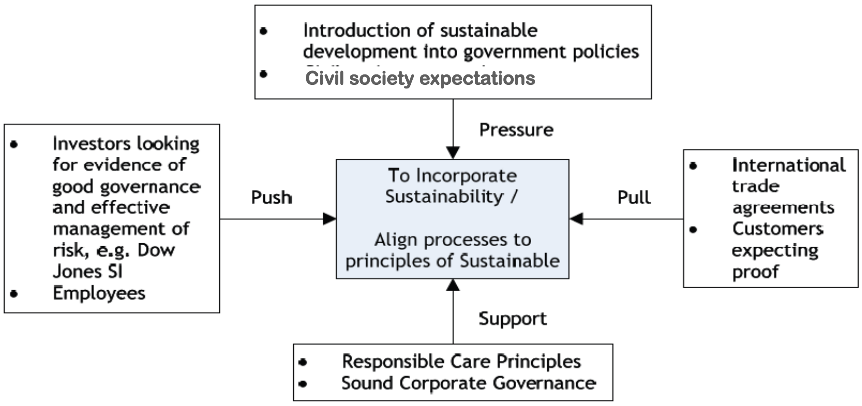

Fig.1.3: The drivers of sustainable development (Source: adapted from Goede as cited in Brent, 2008)

These sustainability drivers can provide focus to the TA which can steer this assessment towards highlighting of sustainable impacts of technology and provides TA with linkages to sustainability.

1.2. Rationale for the study:

These are areas on which focus must be placed in order to improve strategies for the sustainable development problem by improving current methodologies.

1.2.1. Technology assessment as a means to improve strategies for the sustainable development problem

When exploring the domain of technology management, to focus specifically on the comparison and evaluation of differing technologies and their diverse applications one arrives at the discipline of TA which consists of a body of knowledge providing methodologies aimed to present structured approaches of assessment for decision-making and problem solving.

The TA body of knowledge found its inception from the policy needs of the United States Congress during the 1960s (Tran and Diam, 2008), which resolved to better understand the impact of new technologies and the introduction thereof on economic, political, social and even ethical fields. Thus, decision making frameworks and models were developed to assist policy development. These frameworks captivated industry due to their ability to evaluate different technologies primarily for its financial gains, which was focused on short-term approaches, compared to the long-term outlook of governments (Coates, 2003). This led to a division within TA into two distinct areas: methods for long term governmental policy or public sector decision making domain, and methods for corporate, business, or industrial application (Tran and Diam, 2008). TA has always been a tool used to assess and quantify the various impacts of technology with emphasis on the downstream effects of technology's invention and evolution (Coates, 2003).

A major concern, despite the broad acceptance of TA, is the apparent deficient use and application of TA by industry or at least less so than would be anticipated. This is made evident by literature reviews and research development within this area, and specifically in the African context (Musango and Brent, 2010). This raises questions about the simplicity, ease of application, costs and the perceived benefits which is ascribed to these methods.

1.2.2. Sustainability assessment as a means to improve strategies for the sustainable development problem

Singh *et al*. (2008) reiterated the need for an integral systematic approach to the development of indicators so that the definitions and measurements are recognised (Bossel, 1999) in order to give well-structured methodologies, easy to reproduce and assure that all the important aspects are included in the measurement. Singh *et al*. (2008) also warn about the need for clearly defined definitions for sustainability and policy goals before any methodologies and criteria are produced. This appears to be even more difficult as the development of indicators was initiated while there were still arguments over what constitutes sustainable development and thus no clear understanding of what needed to be developed

The primary objective of frameworks and indicators is to summarise, focus and condense the enormous complexity of our dynamic environment to a controllable amount of significant information (Godfrey and Todd, 2001). By visualising phenomena and highlighting trends, frameworks simplify, quantify, analyse and communicate otherwise complex information (Warhurst, 2002).

Therefore, the objective of a sustainability assessment is to offer decision-makers with an evaluation of socio-environmental systems in short- and long-term perspectives locally and internationally in order to support them to determine which strategic actions would lead to a sustainable society (Kates *et al*., 2001).

A view to modify existing approaches may lead to the solution, as have been undertaken through the modified Balanced Score Card (Figge *et al.,* 2002) and modifying Goldratt's Theory of Constraints (Birkin *et al*., 2009). These authors made use of widely accepted methods, which they modified to achieve new outputs while retaining much of the original's underlying logic; thus creating a sense of credibility. This perception can have a definite impact from a market uptake point of view as a practitioner maybe more likely to engage with methods with which they have had similar experience in the past.

Recommendations to focus on further development of technology assessment methods are to be heeded and can be drawn from modifications of analytical techniques such as the Technology Balance Sheet that explore the dynamic interactions between economics, nature and society, as researched in the relatively new field of sustainability science (Brent and Pretorius,2008).

These conclusions were also generated from further research initiated by Brent and Rogers (2009) after an investigation of a rural mini-hybrid renewable energy case study; they highlight the value in looking at the conventional technology assessment methodologies, more specifically at modifying the Technology Balance Sheet.

1.3. Research problem

TA has been indicated to be highly complex and a tedious process with most methodologies requiring specialised skills in mathematical and scientific analysis (Azzone, 2008). The rational of this study holds to the logic that if TA can be simplified and formalised, by making used of widely utilised methods, industry would apply TA generally as a methodology to assist in management decision making. This will be investigated through the application of a new TA tool developed for rapid assessment, if limited in mathematical rigour to provide solutions to initial strategic decision making processes.

It has also been indicated by comprehensive studies on available and applied TA tools and techniques (Tran and Diam, 2008; Singh, 2008) that an increasing amount of tools and methodologies are introduced in the field of technology assessment and sustainability assessment, and that those methods and techniques reviewed were found to be mostly developed by researchers, not industry and modified to suit a particular sector or narrow technical views.

1.4. Research objectives

TA has always been a tool applied to assess and quantify the various impacts of technology with emphasis on the downstream effects of technology's invention and evolution (Coates, 2003). It is the aim of this study to improve the methodologies of TA towards greater sustainability and to provide decision-makers with methodologies based on RETs industry examples that can provide the necessary methods and framework for industry at large to use TA's to assess opportunities that current technologies provide in the market.

Shortcomings exist in the application of current technology assessment tools and methods and how these relate to sustainability. If real value exist in the application of sustainability methodologies, hence current industrial demand for sustainable practices, why have more not been done to incorporate TA into sustainability methodologies and vice versa? Does this indicate the lack in the generic use and application of TA to be used by industry to conduct meaningful analysis (with TA) and allow them to make informed decisions? Thus refocusing the aim of this investigation, to improve the methodologies of TA to address the principles of sustainability and to provide decision-makers with generic methods based on learning from proposed renewable energy technology (RET) interventions in South Africa.

The objective of this study is subsequently to develop a rapid technology assessment tool that can be used in the evaluation of technology as a solution to the sustainability problem. The technology assessment tool should allow decision-makers to rapidly as well as cheaply assess the viability of solutions to further understand the benefits associated with the technology in order to adopt the technology as part of their operations and businesses. The new model could potentially guide further research to more tailored technology assessment models that ensure commercialisation of available and new technologies. The simplicity and flexibility of the tool should extend to include intuitive communication to be used by non-technical stakeholders through a facilitated implementation process. The inclusion of system thinking and complexity awareness should be attained by the utilisation of the life cycle approach and the development of technology value chains for specific domains investigated.

1.5. Research structure:

By initially investigating and formalising both the research problem and the research objectives one is able to start drawing conclusions surrounding the research strategy and the structure which need to be followed. The research strategy is discussed within Chapter 4 and a conventional research structure is applied to communicate the various outcomes in a structure and logical fashion. The remaining section of this report follow the conventional research structure and includes:

- Chapter 1: as an introductory chapter which discusses on the cross-disciplinary nature of this investigation.
- Chapter 2: focuses on the literature reviewed to identify shortcomings and to draw logical conclusions regarding the body of knowledge.
- Chapter 3: defines the objectives of the research and formulates the conceptual framework of the study.
- Chapter 4: develops the research strategy to meet requirements.
- Chapter 5: applies of generated knowledge to specific case studies.
- Chapter 6: highlights the conclusions generated by the new methodology.

A brief over view of the research structure is provided by Figure 1.4:

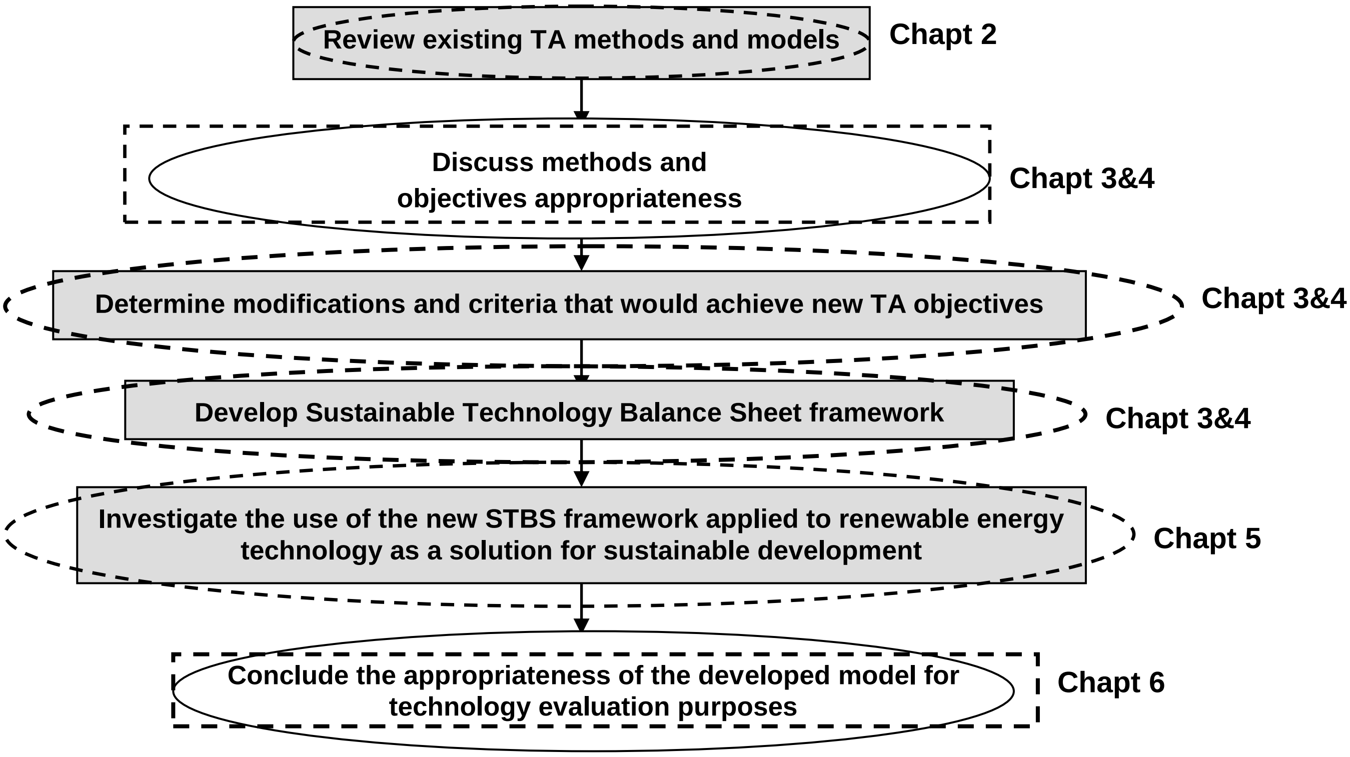

Fig. 1.4: Research structure indication the focus of the chapters within this report.

2. Literature Review

In addition to the first chapter, this section provides a brief review of current TA methods and the evolution thereof. Due to the overwhelming number of comprehensive reviews produced of late, a simple overview and structured literature backbone was found to be more valuable than a reiteration of past learning. To aid the reader in better understanding TA, a brief description in the form of definitions of concept, valuation and application can be provided by various commentators and how these commentators have influenced the field of TA

2.1. The history and development of TA

After the establishment of the USA Congressional Office of Technology Assessment (OTA) in 1972, forms of formal energy technology assessment began to take shape. These were defined as a "comprehensive form of policy research that examines the short and long-term social consequences of the application or use of technology" (Janes, 1996 and Wood, 1997). The OTA viewed energy assessment as one which would emphasise "efficiency" in production and use of energy (Musango and Brent, 2010). The intent was to get earlier awareness and better understanding of what might be the social, economical, political, ethical and other impacts of the introduction of energy technology into society. Thus much time and resources were devoted by the OTA for conducting assessments of energy technologies including a study of an energy assessment for developing countries (Musango and Brent, 2010).

The objectives of which were:

- Understanding the scope at which technology can provide energy services.
- Meeting the needs for social and economic development in developing countries.
- A cost effective and socially viable methodology.
- Evaluating the role of the US in accelerating the adoption of such technologies by developing countries

The main application of energy technology assessment was to make specific decisions pertaining to particular policies and practice of sustainable. This result includes a refocusing of technology assessment into ecological, economic and social impacts (Assefa and Frostell, 2006).

This view was held by many contributors and developed further as can be seen from the following discussions:

Coates (1976) defined TA as "the name for a class of policy studies, which attempt to look at the widest possible scope of impacts in society with the introduction of a new technology. Its goal is to inform the policy process by putting before the decision maker an analysed set of options, alternatives and consequences." More recently Coates (2001) redefined TA as "a policy study designed to better understand the consequences across society of the extension of the existing technology to the introduction of a new technology with emphasis on the effects that would normally be unplanned and unanticipated." These statements create the perception that there is little commercial value within TA for business and industrial applications which limits its applications for the commercialisation of new technologies and technology forecasting which are invaluable to businesses.

Palm's (2006) work clearly indicates that the reason for the existence and development of TA was to determine the effects of technology development. It is important to understand that this is where TA has its origin, from a need to understand future impacts. A summary of the development of TA over the last four decades is given (Table 2.1) and provides the historic development in relation to the geographical parts of the world.

Table 2.1: The development of TA over the last 4 decades (Palm, 2006)

Period	USA	Germany	Other Countries
1960s	The term "Technology Assessment" is used for the first time		
1970s	TA becomes synonymous with the OTA praxis-classical TA	TA is started with the OTA as role model	
1980s	OTA continues to dominate the field	TA is developed as a strategic framework concept and Innovative TA (ITA) is first discussed	Participatory TA (pTA) emerges in Denmark and Constructive TA (CTA) in the Netherlands
1990s	In 1995 the OTA is closed down	ITA becomes influential. Interactive TA is discussed under various names	Privacy Impact Assessments (PIA) become common
2000s			Tentative attempts to introduce ethical issues in TA

Note: OTA refers to the Office of Technology Assessment

According to Palm, during the 1960s a need for greater social responsibility was felt within technology development due to the increased awareness of significant social and environmental problems attributed to new technologies.
The materialization of organised TA was principally an effort to gain political control over prospective negative effects of technological development. This was accomplished by means of forecasting the unintended negative consequences of technical innovations in order to facilitate more adequate policy-making.
Thus this provided forward thinkers with insights which may otherwise have been overlooked.

Similarly van den Ende (1998) defined technology assessment as:

• “*a class of policy studies which systematically examine the effects on society that may occur when a technology is introduced, extended or modified. It emphasizes those consequences that are unintended, indirect or delayed*”.
• “*Technology assessment is an attempt to establish an early warning system to detect, control, and direct technological changes and developments so as to maximize the public good while minimizing the public risks*’’.

This precludes to the predisposition of negative technological effects only becoming evident long after it has been implemented. The need for tools to clarify policy-making is thus evident (van den Ende, 1998).

As a measure of how successful TA is within the public policy sector the following quote summarises sentiments: “*In the long run, TA will be judged to be a successful enterprise only to the degree to which it aids societal decision-makers to identify and choose technology policy options which facilitate achievement of societal goals while inhibiting the potential for unintended negative effects. This requires that TA devote significant, serious and creative effort to the generation of policy options*.” (Berg, 1976).

During the review of literature it becomes evident that there is a clear distinction within TA as to its intended utilisation. The overwhelming focus of the assessment has been policy creation within the public sector and very little has been said for TA in the assistance of industry in commercial technology decision making. It is at this juncture where a shift in focus is of paramount importance so as to aid further conceptual discovery.

Searching for comparisons between TA, from a public sector or policy perspective and TA used by commercial industry, have led to the research conducted by Maloney (1982). This study includes the main differences between public and commercial TA and compares factors such as objectives, structure, timeframes and other perceptions of TA between the sectors. Table 2.2 reflects his comparison.

Table 2.2: Comparison of private and public sector TA (Maloney, 1982)

INDUSTRIAL	GOVERNMENTAL
OBJECTIVES	
Profit maximisation	No interest in profit
Conflict identification and positioning	Conflict identification and resolution
Market diversification based on customer needs	Market creation based on social welfare needs
Identification of customer needs	Balancing public needs
Corporate direction setting	Formulate public policy options
STRUCTURE	
Flexible Process	Highly structures series of steps
Ad hoc mission orientation task force	Formally organised group
Mostly internal effort	Mostly external effort
Private, oral report	Public written, published report
TIMEFRAMES	
Short to mid-term view	Generally long term view
Study takes < 1year to complete	Study takes > 1 year to complete
OTHER PERCEPTIONS	
Complete thinking	Holistic thinking
Accountable to stockholders	Multiple accountabilities
Survival of firm	More rational government
Competitive environment	No competition

The differences between these factors clearly indicate the challenge faced to address the diverging needs of each sector and provides difficulties for standardisation during conceptual planning for the development of new tools. Flexibility is thus critical.

Within the business perspective, one can generally describe four conditions which would necessitate the need for TA, these four conditions form the underlying basis for commercial TA occurring as the following within businesses. Firstly, TA becomes important to businesses when exploring new ventures or to capitalise on new technology. Secondly, TA allows a company to look at both the primary and secondary impacts of its activities. Thirdly, to provide a centralised mechanism used to conduct the TA done by an ad hoc, mission-orientated task force. Finally, when the perspective is future orientated to include an alternative futures approach for the assessment of impacts and transformations. The bottom line performance is an important driving force for the study, as is Risk Assessment with go/no-go decision based on an understanding of the risk involved in the venture (Maloney,1982).

As a result it appears that TA is still not fully utilised by industry to highlight the added value of technologies for commercialisation but merely to highlight impacts for strategic decision making and not to guide the commercialisation investment process from an early stage.

Various TA procedures and guidelines have been developed to aid the practitioner during the assessment process. These include the National Science Foundation (NSF) and the ten elements of a comprehensive technology assessment (Coates, 1976; Coates, 2001). These procedures indicate the scale of commitment required to undertake TA and the relevant resource intensity. Palm (2006) also comments on technology assessment as being resource intensive and that the quality of the outcome seems to be proportionate to the financial means available.

The components or elements of a comprehensive TA, include
(NSF and Coates, 1976; 2001):

1. Examine problem statements
2. Specify systems alternatives
3. Identify possible impacts
4. Evaluate impacts
5. Identify the decision apparatus
6. Identify action options for decision apparatus
7. Identify parties at interest
8. Identify macro system alternatives (other routes to goal)
9. Identify exogenous variables or events possibly having an effect on 1–8
10. Draw conclusions and recommendations

The desired outcomes and actions of a successful technology assessment include (Coates, 1976; 2001):

1. Modify project to reduce disadvantages and/or to increase benefits
2. Identify regulatory or other control needs
3. Define a surveillance program for technology as it becomes operational
4. Stimulate R&D to:
   (a) define risks more reliably;
   (b) forestall anticipated negative effects;
   (c) identify alternative methods for achieving goals of technology; and
   (d) identify corrective measures for negative effects
5. Identify control needs
6. Encourage development of a technology in new areas
7. Identify needed institutional changes
8. Provide sound inputs to all interested parties
9. Identify new benefits
10. Identify intervention experiments
11. Delay project
12. Identify partial or incremental implementation
13. Prevent technology from developing (an unusual but not impossible outcome)

As indicted by the desired outcomes and components the development of a rapid technology assessment is no easy task as significant participation, time and resources is required to generate the outcomes generally expected for TA's.

A further concern for TA is whether the current technological demands have outstripped the capabilities of current TA methodologies. As society is now completely dependent on technology - to meet economic and social demands, to maintain and improve standards of living, and all of which while limiting the environmental degradation from the pressure of population and urban living. The global economy is fuelled by innovation and competition. Therefore, technology is an inextricably linked component for the sustainability of all systems on the planet (Coates, 2001). The challenge for TA can be refined by stating that TA projects can differ by mission, subjects and problem of assessment. The design, structure and methodology are based on these variables and have to be reviewed on a case-by-case basis and modified accordingly. A call for a general TA process are to be heeded and further investigation are required as done in the 1970s (Fleischer, 2005).

2.2. Technology assessment models and methodologies

Park (2004) provides understanding and insights towards technology and its assessment, through the definition of concept and its application:

"*First, technology is neither visible nor tangible. It is frequently embodied in human knowledge or in physical assets and hence difficult to identify the exact contents and scope. Secondly, economic value of technology is affected by various non-technical factors and realized only after it is commercialized to market (Tipping et al., 1995). Therefore, it is an intractable task to quantify and prioritise the link between technological research and commercial payoff (Kash, 1997). Thirdly, valuation is a subjective activity. Value is very much like beauty that is framed in the eye of beholder (Boer, 1999). Furthermore, technology is traded in a supplier's market and thus hard to reach balanced price through market mechanism. Indeed, there are a number of traps or pitfalls in valuing technology that technology managers may encounter.*"

This intrinsic complexity makes TA a very difficult task fraught with subjectivity and uncertainty. The resilience of a system acted on by a technology also becomes difficult to predict.

A number of studies have provided comprehensive reviews of technology assessment tools and methods (e.g. De Piante Henriksen, 1997, Tran and Daim, 2008) for public decision making sector and the rapidly growing business and non-governmental field. Due to the apparent gap within business orientated methodologies, Table 2.3, summarises as the primary TA methods applied in both the business and in public decision making field. As an overview of the tools deemed to be of importance within the scope of this investigation, the different methods and associated tools have been summarised to provide a brief description of the fundamental approach of the method, and also the tools applied within each method:

Table 1.3: Tools and methods for technology assessment

Economic Analysis *Cost benefit analysis* *Cost effectiveness analysis* *Lifecycle cost assessment* *Return on investments* *Net present value* *Internal rate of return* *Breakeven point analysis* *Payback period analysis* *Residual income* *Total savings* *Increasing returns analysis* *Technology value pyramid* *Real options* *Technology balance sheet*	**Information Monitoring** *Electronic database* *internet* *Technical/ scientific lit reviews* *Patent searches* *IP asset valuation* **Technical performance assessment** *Statistical analysis* *Bayesian confidence profile analysis* *Surveys/questionnaires* *Trial use periods* *Beta testing* *Technology decomposition theory* *S-curve analysis* *Human factors analysis* *Ergonomics studies* *Ease-of-use studies* *Outcomes research* *Technometrics*
Decision analysis *Multicriteria decision analysis* *Multiattribute utility theory* *Scoring* *Group decision support systems* *Delphi/group Delphi* *Analytic hierarchy process* *Q-sort* *Decision trees* *Fuzzy logic*	**Risk assessment** *Simulation modelling and analysis* *Probabilistic risk assessment* *Environ, health and safety studies* *Risk-based decision trees* *Litigation risk assessment*
Systems engineering/ systems analysis *Technology system studies* *System dynamics* *Simulation modelling and analysis* *Project management techniques* *Systems optimization techniques* *Linear, integer and non-linear programming* *Technology portfolio analysis*	**Market analysis** *Fusion method* *Market push/pull analysis* *Surveys/questionnaires* *S-curves analysis* *Scenario analysis* *Multigenerational tech diffusion*
Technology forecasting *S-curve analysis* *Delphi/ Analytic hierarchy process/Q-sort* *R&D researcher hazard rate analysis* *Trend extrapolation* *Correlation and causal methods* *Probabilistic methods* *Monte Carlo simulation* *Roadmapping*	**Externalities/impact analysis** *Externalities analysis* *Social impact analysis* *Political impact analysis* *Environmental impact analysis* *Cultural impact analysis* *Integrated impact assessment* *Life cycle analysis*

(De Piante Henriksen, 1997, Tran and Daim, 2008)

The scope of the review was generated from the initial conclusions drawn from the project discussions pertaining to the project including, its frame of reference and the most valuable literature surrounding the problem statement. It was felt that the first port of call for an in-depth investigation should be focused on other assessment tools within the TA body of knowledge with specific emphasis on the methodologies earmarked to be utilised and ultimately modified for sustainability. A concrete overview of the Technology Balance Sheet methodologies was thus pursued to enable this project to add the maximum value to the existing framework as well as to the body of knowledge. Subordinate methodologies which were also deemed to be useful were also investigated to augment the primary strategies including Technology Road Mapping and Multi Criteria Decision Analysis.

Technology Balance Sheet (TBS):

The TBS is a graphical representation of the interrelationships, inter-dependence and reliance between the factors of technologies, processes, products, and markets. The foundation for the TBS is the relative relationship between these four factors. Originally the relationship was based on economics and how the factors met each other's demands (de Wet, 1992).

The simplistic logic of the framework, which is indicative of the relationship between the factors considered, makes use of a simple matrix to relate two specific factors. This is then augmented by other matrices to enhance the relationship or connection between factors while still retaining the straightforward logic behind each matrix (Figure 2.1).

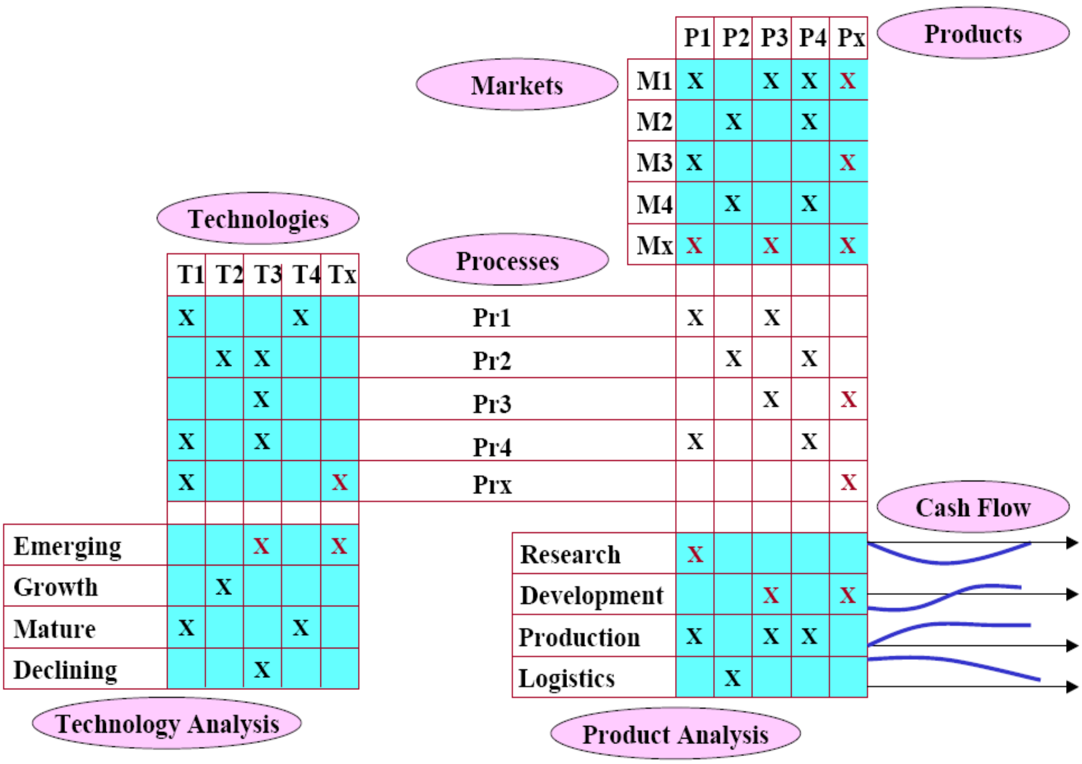

Fig. 2.1: The original Technology Balance Sheet (de Wet, 1992).

Within this framework, new technology is either incorporated into existing processes or generates new processes to produce products, which either meets an established market demand, or creates a whole new market niche. The technology thus acts as a driver for new products and processes due to its enabling characteristics needed for existing products and process. This defines the connection between the four factors through the interconnected nature of the factors (De Wet as cited in Grover and Pretorius, 2008).

The TBS is a business-orientated tool designed to aid managers in the technology decision making process. The tool intends to facilitate and guide an enterprise through a technology assessment process towards a clearer understanding of the conclusions ultimately produced by the framework. The enlightenment generated by the process is often more valuable than the outcome obtained. This would include a better understanding of how organisational structures relate to each other and how operational flows affect the business, both by means of a greater internal and external awareness.

This said, the TBS will still be a communication tool that can effectively convey the outcomes to those not involved in the process, including non-technical stakeholders, who will be able to draw logical conclusions and intrinsically reach the correct answer, which is so important for personal buy in and ultimate project success (De Wet as cited in Grover and Pretorius, 2008).

The TBS is traditionally designed to provide the “technology manager” with the means to gain insights into an understanding of the technological environment and thus be able to decide upon which technologies to choose for future utilisation (de Wet, 1992). An assessment is conducted on issues including present technologies, market dynamics and product maturity.

The TBS answers the questions of “where are we” as business looking at technology and provides strategic direction by answering “where to go” as well as “where to get out” by making use of technology s-curves and analysing where a technology is located in the technology life cycle (de Wet, 1992).

The TBS indicates the forces at work within the techno-economic system. These forces manifest themselves within the organisation as opposing directional forces, simply as a push or a pull (de Wet, 1992). These forces are produced by different elements within the factors. A market force can be described as a pulling force pulling business output towards the market demand, be it though desired products, which occur only once the force has been transmitted to the processes to generate the capabilities within the business. However the production of these products and the developing of these processes only occur once the pull force has been transferred into the technology factor to grow, develop and provide the technologies and methods required to generate the processes required to create the products to

meet the market need. If one considers technology as a push force we can experience a force from a new technological invention or development pushing along new capabilities and new processes, which can lead to new or advanced products and through their existence create new markets or change the dynamics of existing ones (Figure 2.2).
These two forces can have a feedback effect on the entire system as the process and capabilities continue to grow and so a type of causal loop system is created.

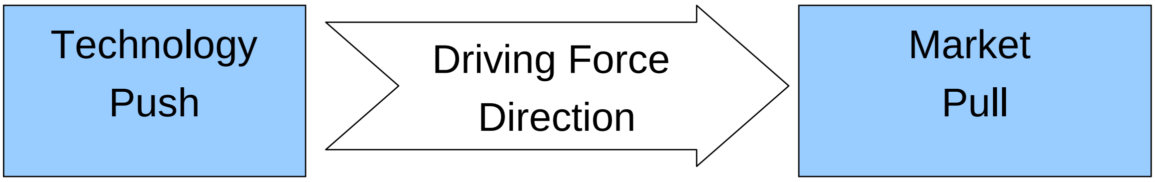

Fig. 2.2: The TBS underlying drivers (modified from de Wet, 1992)

The TBS provides organisational value by highlighting the drivers at work within the organisation and how these can be manipulated to be successful in meeting the business goals. As one becomes more aware of how each factor relates to the others, one is more able to grasp their impact. This would not only be unique to being economically successful, as is the traditional intent of the TBS, but by reviewing the intent, aligning the point of view and reassessing the goals one will be able to use the simple TBS framework to meet any desired outcomes, which in this study is to address sustainability while critically assessing the different technologies.

Therefore sustainability of technologies in the TBS can be introduced by making use of the principles or criteria used for the assessment of environmental, social and economic sustainability. This would include criteria applied in the broad sustainability body of knowledge (Singh *et al.*2008) and refined during the needs analysis through stakeholder engagement.

As stated TA methodologies have specific shortcomings and the TBS is no exception. Specifically the TBS does not intrinsically take sustainability science principals into account and thus does not intrinsically rate technologies according to factors relating to society, the economy or nature. Sustainability must therefore not be a bolted-on addition to the TA but central to the proposed methodology and ultimately to its goals.

Apart from not intrinsically taking sustainability into account, TA has also been criticised for other perceived weakness or inabilities, which may be impart due to its own success. These include aspects of being very case specific, which are not always easily adapted to other environments and may create barriers of perception between various sectors thus biasing operators to sector related methodologies.

A second trade-off comes in the form of rigour versus rapidity. There are a variety of excellent TA tools available, which can provide broad understanding of the problem, address it comprehensively and provide outcomes that can rigorously stand up to any scrutiny. These tools are however very time-consuming and thus very expensive which in some cases limit their appropriateness and thus their effectiveness.

The following three paragraphs briefly deals with specific methodologies which maybe able to contribute to the investigation, as they form the bases of a variety of pre-existing and utilized tools. These methods were briefly reviewed to ascertain their importance in the development of a new tool as well as to provide an understanding of the fundamentals involved in each. These can form a small part of the underlying logic of the new framework:

Technology Roadmapping:

Roadmapping is defined as primarily a management tool used for project forecasting and strategic scheduling. As stated by van der Merwe (2009), the core concept of roadmapping is a structured and facilitated process involving a diverse and multidisciplinary group of experts to generate a visual strategic plan in the form of an analytical framework or structure that shows how the different technological factors interact, influence each other or are constrained by technical, social and economic factors. This architecture takes on many forms as frameworks which are specific to the technology evaluation that it is applied on (Phaal, *et al*, 2004).

Multi-criteria Decision Analysis:

With decision analysis multi-criteria decision making analysis gets conducted to compare various options against each other and identify the strongest based on criteria chosen. Ananda and Herath (2009) describe MCDA as a structured framework for investigation of decision problems containing multiple complex goals. This includes uncertainties, risks and complex value issues. The MCDA process describe objectives, develops the criteria to measure the objectives, indicate alternatives, transforms the criterion scales into measurable units, assigns weights to the criteria that denote their relative importance, utilises a mathematical algorithm for ranking alternatives, and selects an alternative. Other useful decision tools include: Analytical Hierarchy Process (AHP) and Monte Carlo Simulation.

Technology Evaluation:

The tools associated with this particular methodology make use of the performance characteristics for selected key attributes of the product, process, and technology to compare alternatives. The tools include: Functional analysis, Technology evaluation metrics and Parameter development specific to technology used in comparison.

Insights from TA:

TA is made up of a large number of independent methodologies and tools which are applied in isolation or jointly as the situation dictates. It can thus be concluded that an integrative approach utilising various tools to access their various benefits would reap rewards and provide benefit to the field of TA.

As stated before the goal of TA was to provide impact forecasting for specific technologies. Originally this was viewed with high expectations to provide insights for the total number of factors which would contribute towards sustainable technology systems. However due to the resource intensive nature of TA these goals were seldom achieved and the outcomes fell well short of addressing the original sustainable objectives. The need for a focusing exercise was identified, which could steer the assessment process while remaining moderate in resource utilisation (Palm, 2006). This gives rise to a discussion surrounding the Risk Assessment methodology which is one of the most prevalent TA methods. This method specifically focuses on a defined implementation of a technology like gasification, thus limiting the effects of externalities on the scope of the investigation and do not account for indirect impacts of the technology adequately (Palm, 2006).

Park (2004) utilised a method of standardisation of information for TA by using factors and rates, so as to generate useful decision criteria. He advocated the use of monetary values for technology evaluation, including net present value and internal rate of return calculation. A major obstacle of the method was to overcome the difficulty of understanding theoretical requirements and the uncertainties which these create. Simpler standardisation is required.

Fleischer (2005) is also highly critical of TA's inability to be utilised during the early project staged and not implemented at a late stage where impacts can easily be identified and quantified. His call is again for TA to act as a driver guiding the direction of the technological innovation process towards desired and sustainable outcomes.

2.3. Sustainability

Within this section the aspects of sustainability are briefly highlighted. Sustainability has also been discussed within other chapters as well as within the Appendices A and B, where further information and more technical details may be obtained. This section creates an overview of sustainability for the rest of the study.

Assefa and Frostell (2007) relate the dynamic growth experienced by sustainability concepts within literature over the past twenty years driven by a variety of levels within society. Generally sustainability is defined as the interaction of three dimensions or factors namely: economic, ecological and social systems. A fourth dimension is also suggested, namely political systems which is to provide further insights and create “whole sustainability”. Many have advocated the political factor, which describes the governing environment and enable projects to exist, as a sustainability dimension or “Holon”. The concepts behind each sustainability Holon is briefly discussed

- ecological sustainability: the valuation of ecosystem services along with the conservation of natural capital. This can be seen as the resilience of natural ecosystems and the use of sinks for carbon;
- economic sustainability: the equitable existence of economic systems and their efficiencies, to ensure continuous economic progress now and into the future;
- social sustainability: the systems for human interaction and cultural sustainability; and
- political sustainability: the enabling framework for national and international governance.

Thus these viewpoints induce a paradigm shift, away from conventional neo-classical economic perspectives towards a holistic sustainable perspective. This new focus leads the way for sustainable development in which all facets encapsulated by sustainability are addressed, impacts assessed and benefits shared. This is done by scientifically identifying needs, objectives and visions. The focus for additional research on essential limits, boundaries, and thresholds for meeting human needs and preserving life support systems is paramount.

“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).

Assefa and Frostell (2007) also advocate the need for a systems approach to sustainability thus allowing the simultaneous assessment of all the sustainability Holons. This facilitates the evaluation of different technology scenarios by a number of indicators in the same diagram. This may not immediately tell decision-makers which technology they should prioritise. However, it does provide information on the Holon performances of the scenarios using the selected indicators to help them make a more informed decision without risking sub-optimisation. This can establish a new perspective to decision making.

Musango and Brent (2010) indicated that the assessment of technological sustainability is limited and that most studies do not assess the sustainability of the technology per se. Work done to rectify this shortcoming includes Brent and Rogers (2009) applied a sustainability assessment methodology on a renewable energy technological system in South Africa utilising models in the field of economics,

sociology, ecosystem sustainability, institutional governance, and technical energy conversion aspects. Brent and Rogers indicated obstacles to sustainability which require better understanding and further research including the complexity of the socio-institutional sub-system, which resulted in uncertainty for the project planners and system designers and additionally the lack of resilience of the technological system to the demands from the socio-economic and institutional sub-systems.
The clear need for sustainable energy systems is thus critical for sustainable development within the third world. These need to provide the foundations for upliftment as described by the MDG.

Conclusions from the literature:
From the comprehensive review of the TA methodologies and tools, deficiencies and gaps within the body of knowledge have been identified and are summarised as follows: These must be formally stated and further utilised through out the research, by assisting the development of new objectives and action points which are aimed at addressing these shortcomings as well as improving the body of knowledge. The formalised deficiencies and short comings as drawn from the literature review include:

- TA is time consuming, requiring large amounts of resources for accuracy.
- TA methodologies have a narrow focus towards the social impacts and are not integrated to include all sustainability aspects (social, political, financial, technical, operational, environmental, regulatory and market conditions). This has occurred due to the further resource demands which it would create.
- TA is generally very case specific with methods modified for specific assessment applications.
- TA relays heavily on quantitative and qualitative data generated by mathematical and scientific analysis to provide complex information to decision makers.

3. The conceptual framework:

In this chapter the knowledge gained in the literature review is utilised to draw conclusions and objectives to address the shortcomings experienced within current TA and provide a starting point for the improvement of TA methodologies. It is through meeting these objectives that the proposed framework was developed. The structure of the proposed framework is further discussed and the factors, criteria, evaluation and decision making involved with the new method are explained.

3.1. Assessment framework objectives

This section discusses the objectives for the new method based on the conclusions drawn from current TA techniques. This is to aid the practical use and application of the proposed framework. It addresses the following:

Resources and time:

- TA is time consuming, requiring large amounts of resources for accuracy.
- Requirements: Due to the technical and complex nature of TA, in depth studies and long analysis of data by costly personnel is needed
- Objectives: Generate rapid assessments, by utilising qualitative assessments and expert opinions to rapidly focus strategies for further and more rigorous investigations.

Sustainability and integration:

- TA methodologies have a narrow focus towards the social impacts and are not integrated to include all sustainability aspects (social, political, financial, technical, operational, environmental, regulatory and market conditions).
- Requirements: Focusing on only a few aspects of a technology to facilitate a social and economic agendas
- Objectives: Take a systems approach with an unbiased view towards all the aspects which may be impacted on by a technology and assessing these simultaneously.

Generality

- TA is generally very case specific with methods modified for specific assessment applications.
- Requirements: The development of unique methods such mathematical models and untested methodologies
- Objectives: Create a structured approach which provides a guide for customisation and modification while retaining its integrity.

Complexity and data:

- TA relies heavily on quantitative and qualitative data generated by mathematical and scientific analysis to provide complex information to decision makers.
- Requirements include: highly technical skill sets utilised by professionally trained practitioners with access to large data bases with complex data sets.
- Objectives: Simplified analysis that can easily be employed to conduct the required analysis without the need for extensive data mining thus providing information that aids the non technical decision makers.

From these objectives we are required to formulate practical ways to implement these objectives into a new method. These can be viewed as action points or implementation solutions as presented in Table 3.1.

Table 3.1: STBS action points

TA Category	STBS Objectives
Resources and Time:	Generate rapid assessments, by utilising qualitative assessments and expert opinions to rapidly focus strategies for further and more rigorous investigations thus focus on providing strategic direction and effective communication
Sustainability and Integration	Focus on the bigger picture of which the institution or project forms a part and cannot act independently thus take a systems approach with an unbiased view towards all the aspects which may be impacted on by a technology and assessing these simultaneously
Generality	Create a structured approach which provides a guide for customisation and modification while retaining its integrity which can easily applied to a broad set of instances
Complexity and Data:	A rapid and simplified approach using prevalent methods such as matrixes while limiting the exposure to highly technical methodologies. An assessment should occur through reiterative workshops that include stakeholder engagement and expert opinion. Limiting the number of discussions to adjust for rigor or speed. Focus on qualitative data gained from past experience and expert opinion which is tempered by the stakeholder engagement

In conclusion, these action points and objectives are of great importance as they act as, not only the guide to the research study but forms the backbone to the framework development.

3.2. Further research insights:

The rationale of the framework is to propose a rapid technology assessment and communication tool that is developed, modified and executed through a structured information and decision process, which can be followed by various stakeholders. This process can take the form of a workshop approach, which is similar to other workshop-based investigations such as the process undertaken for technology roadmapping. The integration and alignment with existing engagement frameworks or methodologies would be desirable and useful as they can form the preceding activities such as information collection to the proposed STBS. These frameworks were specifically designed to investigate sustainability aspects such as complexity and the resilience of technology systems by looking at the entire value chain and focusing specifically on communities or environments.

Examples of existing frameworks are “The Model to achieve assessable sustainable performance indicators for technology systems” (Brent and Rogers, 2009). This makes use of the Kolb learning cycle to create knowledge focusing on feedback loops that occur at different stages of the cycle, which provides clarity to the associated complexity and indicates system resilience. A learning model was thus created guiding investigations making use of disciplined experts in the fields of economics, sociology, ecosystem sustainability, institutional governance, and the physics and chemistry of energy conversion processes. These experts were needed due to their investigation centring on renewable energy such as mini-hybrid off-grid electrification consisting of solar photo voltaic cells and wind turbines (Figure 3.1).

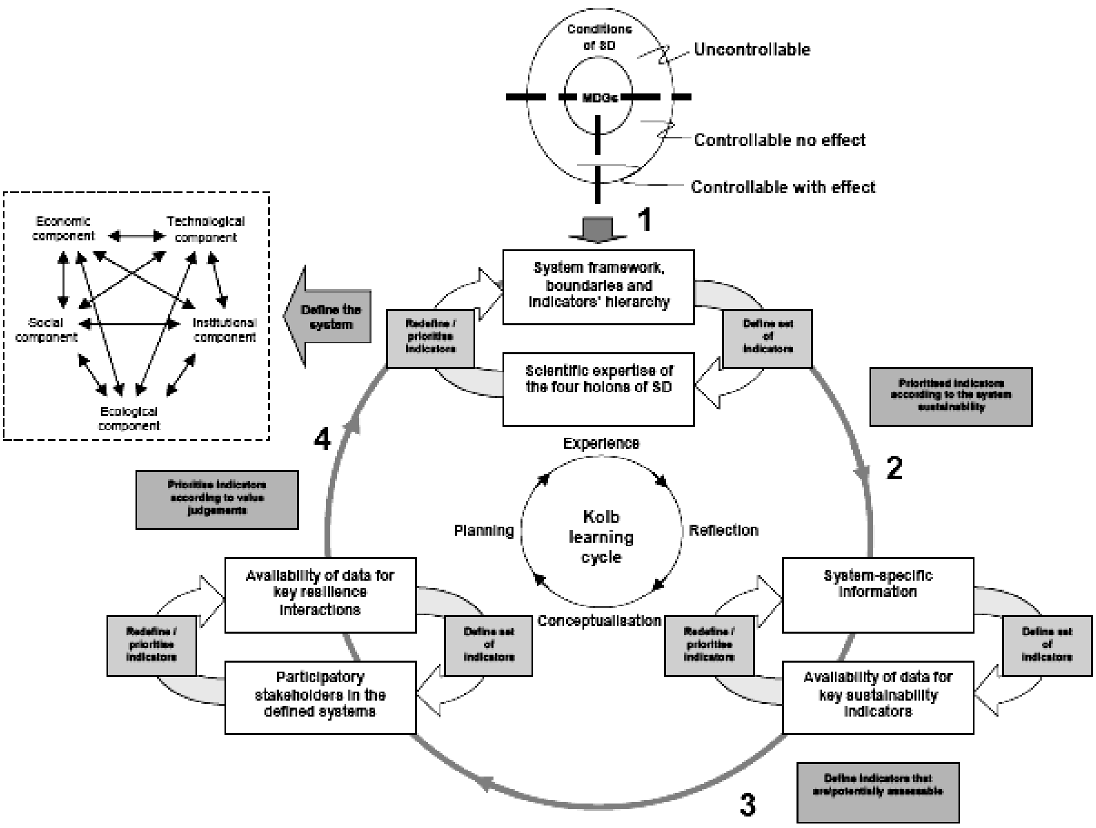

Fig. 3.1: Model to achieve prioritised assessable performance indicators for technological systems (Brent and Rogers, 2009)

A similar model is the Planning for Sustainability Framework described in Figure 3.2, which is a sustainability assessment framework with a bottom-up approach that heavily draws on stakeholder engagement process to leverage relevant system information and orders the group thinking into a useful knowledge state that can be used to generate a sustainable vision with achievable outcomes (Haywood *et al*., 2009).

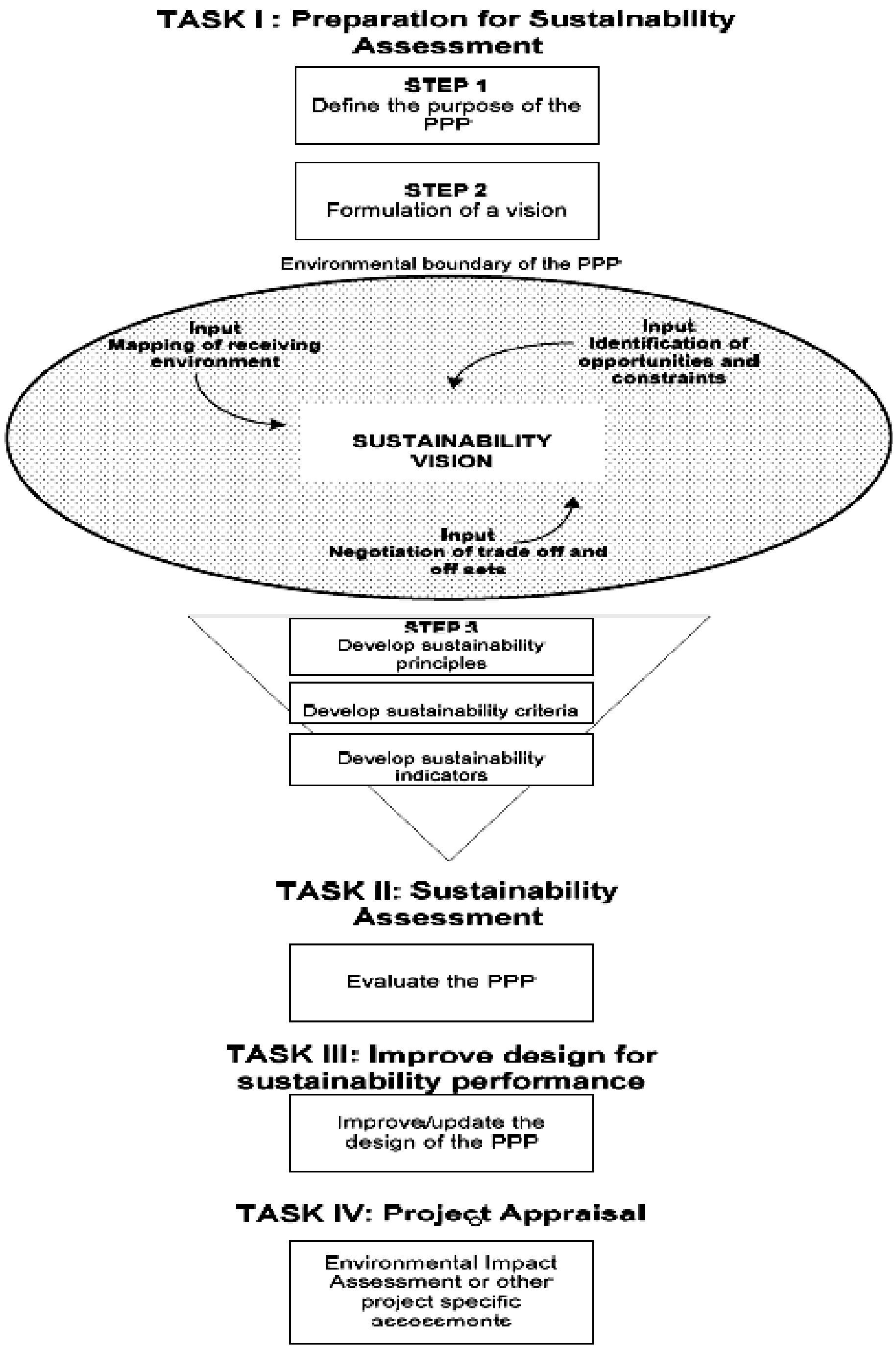

Fig. 3.2: The Planning for Sustainability Framework (Haywood, de Wet, von Maltitz and Brent, 2009)

The usefulness of these approaches are quite apparent because they use a similar process of reiterative thinking that can result in a synergy of modifiable methodologies which can be generically reproduced to ensure system thinking and learning is retained.

There are also direct links between these stakeholder engagement frameworks and the proposed STBS, especially the Plan for Sustainability. They could form part of the same investigation process where outcomes can be used in the later activities such as a STBS with more focus on the technology assessment. They would thus be complimentary within the assessment process, and the STBS may provide additive value to these approaches as well as through its rapid nature and decision making outcomes.

By using this approach the knowledge generated can thus be further utilised to draw conclusions of the technology system thus aiding the “Technology Managers” in making correct, informed decisions. Effectively these engagements will provide some of the raw materials required in an evaluation and decision making process as specified by the STBS.

The initial thinking surrounding the rapid assessment framework can be illustrated by Figure 3.8. The final STBS Implementation process is shown by Figure 3.3.

3.3. Sustainable Technology Balance Sheet framework and Implementation process:

3.3.1. Understanding the conceptual framework

The STBS conceptual framework was developed as a sustainable technology assessment tool known as the Sustainable Technology Balance Sheet (STBS) which is a rapid technology assessment framework and communication tool, which forms an integral part of the preceding step or part, which is referred to as the Implementation process, which is a structured method through which the relevant stakeholders can engage and qualitative data can be obtained for the STBS. Each part consists of specific methodologies and underlying logic, which can be summarised as follows:

- The Implementation process consists of four steps initiated by a facilitator during stakeholder engagement workshops to generate information needed to populate the STBS, create system awareness and project enlightenment among these stakeholders.
    - **Step 1a: Value Chain Generation:** through a life cycle analysis and by the investigation of the product/process life cycle to generate, firstly a generic

value chain and secondly, once the components of the value chain are validated, a case specific process value chain is generated.

- **Step 1b: Sustainability Criteria Development:** Sustainability aspects addressed by stakeholder engagement and literature review. Done congruently during the initial engagement stages. Once systems-thinking has been instilled, discussions surrounding the creation of specific Sustainability Criteria may be fulfilled. This would reaffirm the stakeholders' intentions toward sustainability.

- **Step 2: Technology and Process Awareness**: Achieved through the creation of input-process-output diagrams, which indicate process linkages known as Technology Super Structures. This is done for each one of the value chain components indicated by the dashed rings of Fig 3.8. A short discussion surrounding the grouping or indexing of Sustainability Criteria into sectors may also be accomplished.

- **Step 3: STBS Development**: The utilisation of the generated information and understanding to populate the STBS so as to formalise the information and to communicate conclusions accurately.

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- **Step 4: Strategic Direction and Conclusion Analysis** the presentation of STBS outcomes to relevant stakeholders is of vital importance. This new impetus, created by the indicated strategic direction, needs to be subscribed to and further investigations can be made in an enlightened and qualified direction. These investigations can include MCDA studies and LCA decision trees to add more rigour to the indicated outcomes and strategic conclusions.

The Implementation Process of the STBS and its four steps are clearly illustrated by Figure 3.3 and will be further elaborated on in detail in the following section.

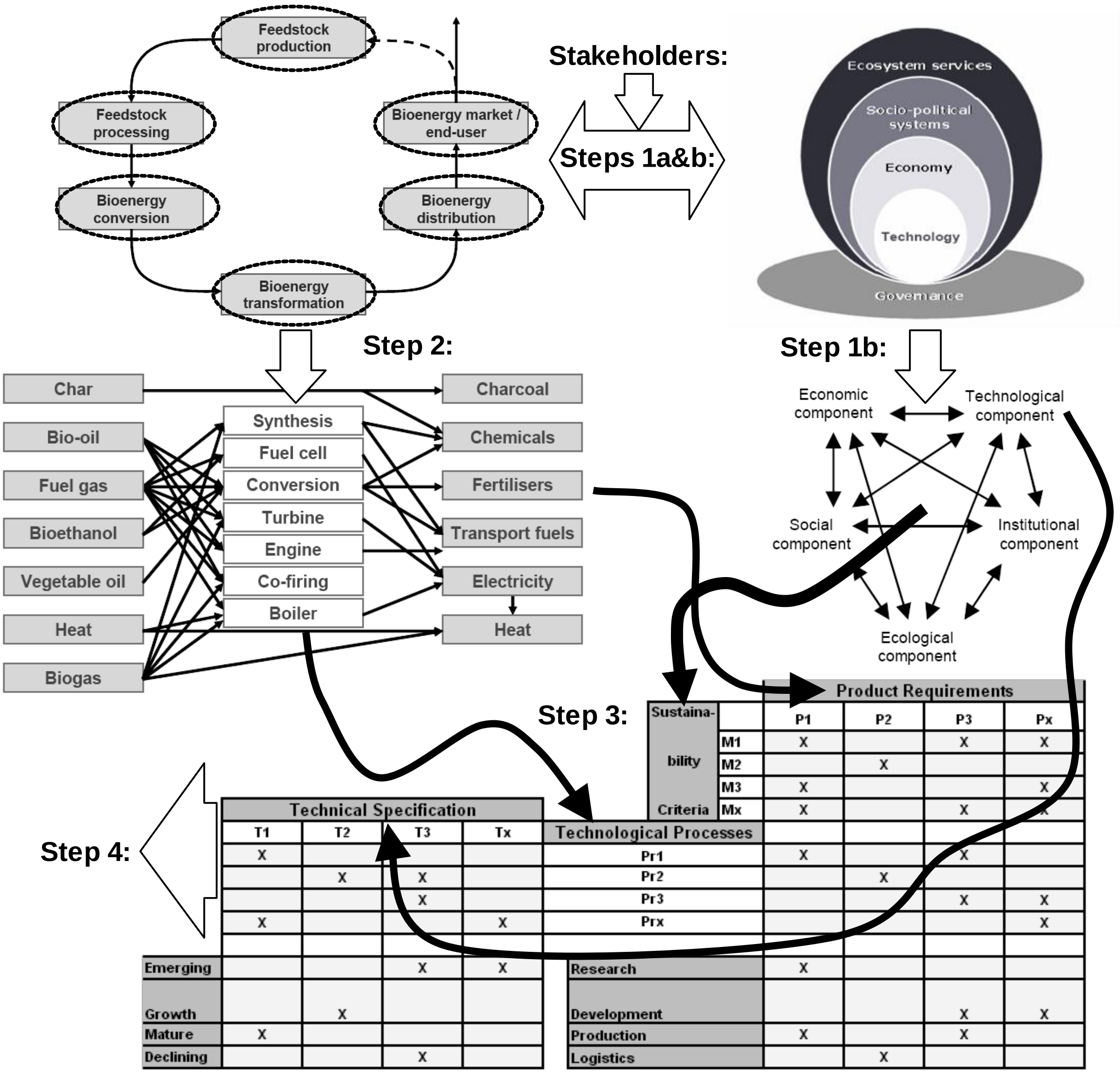

Fig. 3.3: The Implementation process of the Sustainable Technology Balance Sheet

The logic and thinking behind each step will be elaborated on further within this section as well as within Chapter 5, which deals with the different case studies utilised within the trial-and-error phase for an action research strategy. It is mostly from these investigations that the most conclusions could be drawn.

3.3.2. Understanding the logic and method:

Step 1a: Value Chain Generation

Value Chain Generation occurs by the investigation of the product/process life cycle to, firstly, generate a generic value chain and secondly, once the components of the value chain are validated, a case specific process value chain is generated.

Developing a unique value chain or life cycle for the interested technologies of the specific sector. This can be done by making use of and modifying the various generic value chains or life cycles and evaluating where in the organisational life cycle or life cycle relationship framework the focus lies according to the scope of the investigation. If one takes a systems-thinking approach one would evaluate all of the life cycles associated with a technology. Value chain development can be an extensive and time consuming exercise which can more easily be done by duplicating the approach which has been taken here within the limited scope of this study. For this study, the focus was placed only on technologies relevant to the case studies.

In order to achieve this, one must look at organisations in general. A generic project or organisation consists generally of three related value chains namely the Product life cycle, the Process/Asset life cycle, and the Project/Technology Development life cycle, which makes up the organisational life cycle. These life cycles interact with each other through specific relationships. The relationships between the life cycles are illustrated in Figure 3.4.

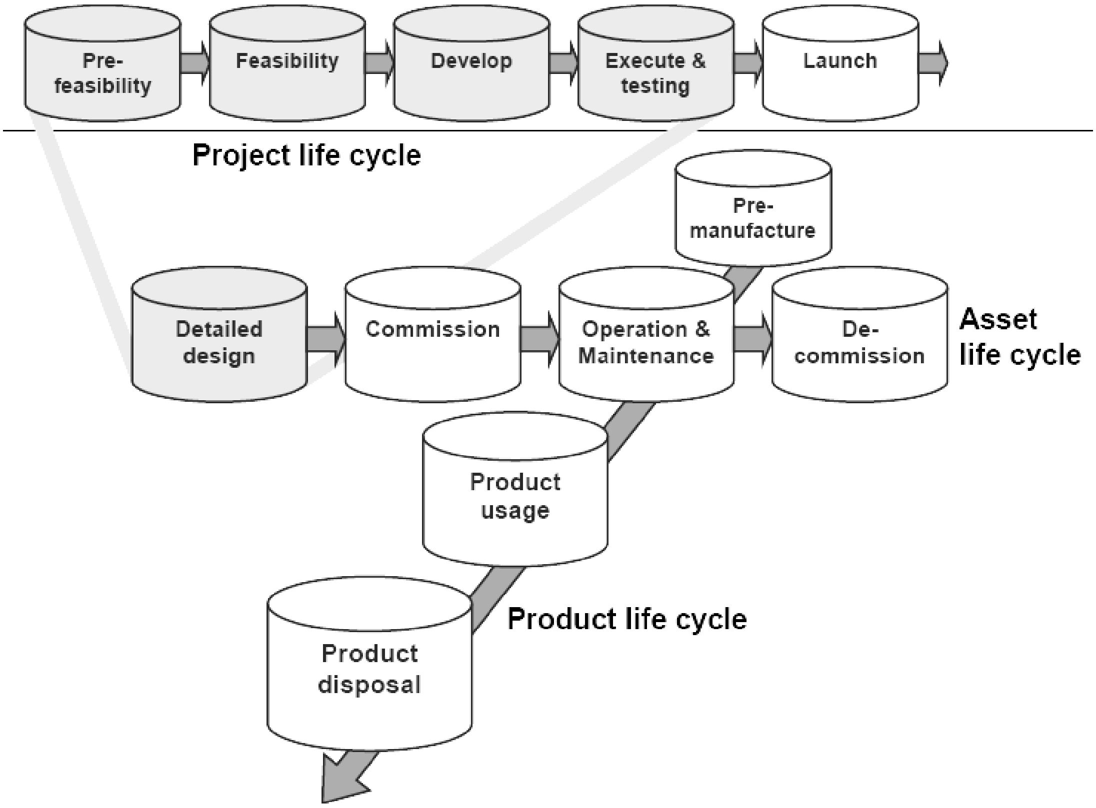

Fig 3.4: The intersecting of the asset and product life cycles and the project life cycle for one life cycle component (Labuschagne and Brent, 2005)

From the above diagram it can be clearly seen that there is a relationship between the Product and Asset life cycles. It illustrates how they are linked through the intersection at the operational field and thus impact on each other at that point. It is there where changes in the upstream fields of the life cycle not only affect the specific life cycle but also impacts on the downstream fields of related life cycles from this linkage point.

The Project life cycle is also seen as a subset of the Asset life cycle and acts as a value gate contributing to the design component of the Production/Asset life cycle as illustrated by figure 3.4 (Labuschagne and Brent, 2005).

The “Technology Funnel”, shown in figure 3.5 (Pretorius and Brent, 2008), relates the various stages followed within the development of a project also indicating the gates through which an idea must pass initially in order to be classified as feasible through R&D, and ultimately business gates that need to reach a demand market. This is a business specific value chain, which again clarifies barriers that an idea or technology will need to address in order to be successful (Pretorius and Brent, 2008).

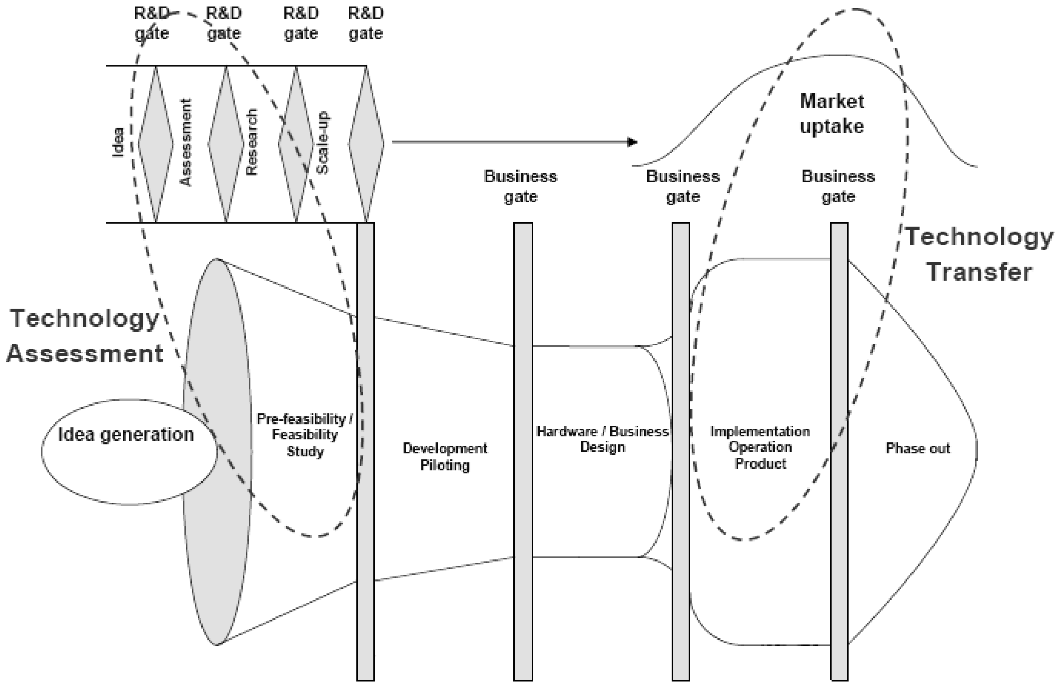

Fig.3.5: "The Technology Funnel" (modified from Pretorius and Brent, 2008)

For the case in point, focus was placed on the bio-energy sector and a modified Product life cycle was produced to highlight the specific components, which requires further investigation. The indicated relationships between the various components create a causal loop, which is indicative of the feedback created within the system as shown in figure 3.6.

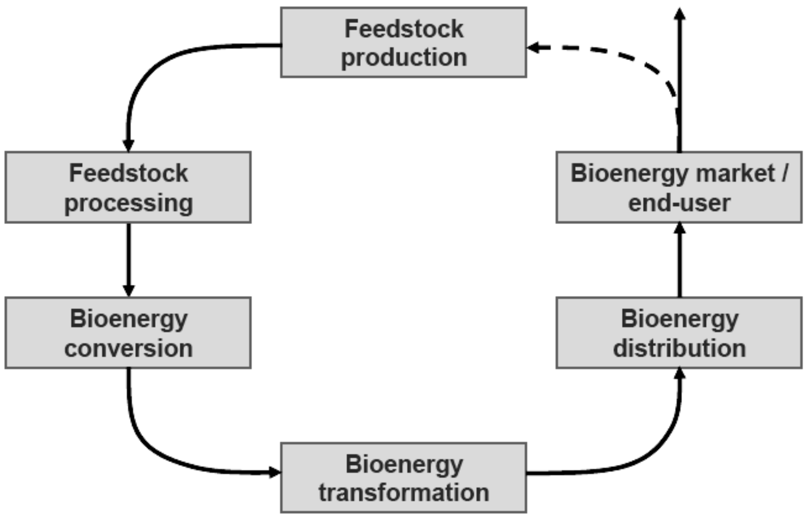

Fig.3.6: A generic bio-energy product life cycle (Brent, 2008)

Step 1b: Sustainability Criteria Development:
Congruently, during the initial engagement stages and once systems thinking has been instilled, discussions surrounding the creation of specific Sustainability Criteria may be held. This could reaffirm the stakeholders' intentions toward sustainability? The Sustainability criteria process is discussed at length within chapter 4 and in Appendix A and B, which provides a clear rationale of the criteria issues as well as providing actual examples which can be utilised.

Once the unique value chain has been developed and the specific component to be addressed identified, a set of sustainability evaluation criteria needs to be produced by the relevant stakeholders. The set of evaluation criteria must relate to the sustainability body of knowledge (Singh *et al*., 2008) and pertain to the specific needs and requirements of the unique sector, and component value chain as ascribed to by the relevant stakeholders and experts.

These criteria then acts as the market pull drivers for sustainability within the market factor of the STBS. This forms the backbone of the technology sustainability assessment process and the cornerstone to which all the other factors within the STBS are related.

How will we address specific technical advantages which one technology has over a rival? This is not addressed in the market factor and is most suited to be unpacked in the process factor and to be evaluated with specific technical criteria which could be created by the stakeholders to add to the rigour of the assessment.

Step 2: Technology and Process Awareness
Once the relevant information has been gathered for each life cycle component, a schematic information diagram can be used to relate the complexity, which has arisen, and to help in communicating this information to stakeholders. These diagrams can take the form of a Super-structure. These illustrate inputs, process and output within each component through a series of blocks and arrows, which communicate relationship connections with great simplicity. A Super structure can be generated (Ayoub *et al*. 2009) for each of the life cycle components, e.g. the bio-energy transformation component of the specific value chain illustrated in figure 3.7 (Brent, 2008).

This is done for each one of the value chain components indicated by the dashed rings of Fig 3.3 A short discussion surrounding the grouping or indexing of Sustainability Criteria into sectors may also be had.

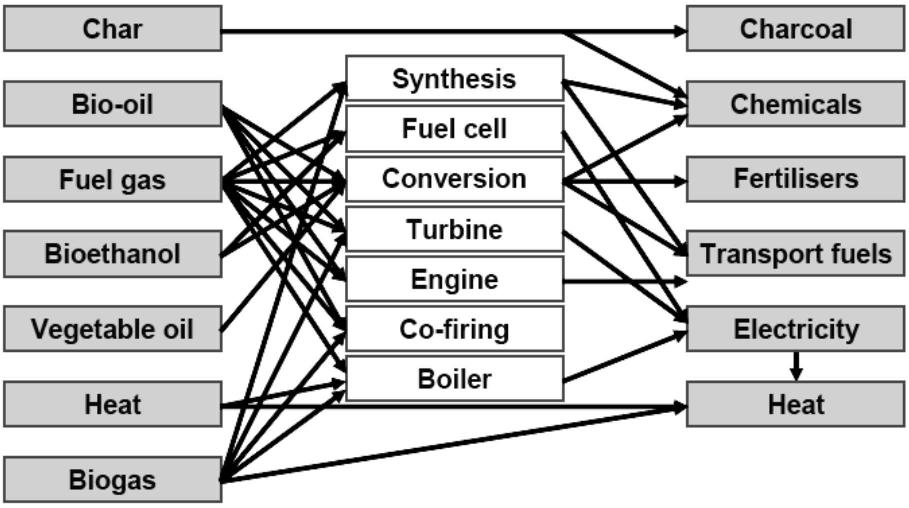

Fig.3.7: The specific primary bio-energy conversion technology life cycle (Brent, 2008)

The Super-structure in its own right is an extremely valuable tool highlighting connections within the system and creating complexity awareness, thus adding value to the process in its own right (Ayoub, *et al*. 2009).

As we can see, the STBS can be populated from two distinct directions or points of view. The technology push arising from the life cycle evaluation and the market pull generated by the sustainability criteria set by the stakeholders for this specific life cycle component.

The required data to populate the technology, process and product factors of the STBS are produced during the creation of the specific life cycle and the evaluation of the components, which make up this value chain.
These components of the value chain consist of inputs, processes and outputs, which are used to populate the factors in STBS.

These can act as drivers to push the organisation forward through products towards the sustainability goals

Is this, however, the correct approach or should it rather be looked at to use only the process aspect within the components of the value chain, the technology aspects as they present in the core of the life cycle evaluation, to populate only the technology factor of the STBS to unpack these further? This approach needs to be discussed with the stakeholders.

Manipulating the STBS towards sustainability is done by making use of the four factors as sustainability portals, drawing four feed-in points from the technology life cycles and the sustainability criteria as sources, which generate force. The

Technology push and market pull force creates the tension required to assess the technological system.

From the evaluation of life cycle stages, the technology and the product, are generated which are then assessed for that component within the STBS. The life cycle component is divided into inputs, processes and outputs. This system clarity is utilised in the STBS. The process in the life cycle component is ascribed to the technology factor and can be assessed in the STBS. Similarly, the outputs within the products factor were used in the STBS to meet the sustainability goals.

During the initial investigations and discussions with stakeholders and experts relating to the understanding around technical aspects as they pertain to the project or case, as well as to the technology assessment and the evaluation process, the fundamental question of "What is the most correct technological choice?" was often the first to be asked. This results in a high-level cognitive process to engage the vast range of criteria and factors to generate some conclusion in the form of an intuitive opinion or gut feel.

This conclusion can be the incorrect one but this is only due to one basic factor, complexity. It manifests as a lack of clear correct information, which is not given in an ordered fashion in which to view the information of the system. It thus becomes extremely difficult to be able to structure one's own decision thought processes to make adequate use of the available information.

Obviously as the process of understanding unfolded, the originally unbiased opinion changed rapidly as the cognitive reference points shifted with new and compelling data that creates an emotional response to the factors and how they were internally prioritised.

This cognitive decision process in not wrong, even if it initially generates the wrong opinions. This knowledge is very useful and should be encouraged within an unbiased open-minded state. The danger does arise if used in isolation as the ultimate conclusion. The cognitive process is a very powerful one, which can be used in almost every situation in which a decision must be made and a plan of action formulated.

One of the first applications of this cognitive process was related by participants as technical aspects, which they had identified to have a significant priority in the evaluation process. These factors do not readily fall into any of the sustainability three pillared approach categories but may be addressed in expanded sustainability approaches, which include institutional and technological factors. It may thus be proposed that these are included in the STBS as the process factor to create a sustainability link between the technology and the product.

Step 3: STBS Development:

The core aspect of the Implementation process is contained within step 3, which is the utilisation of the generated information to construct the STBS. The understanding gained is then extrapolated to populate the STBS so as to formalise the information and to communicate conclusions accurately.

In other words, once the STBS process has been followed the need arises to standardise the data within each of the STBS frameworks for each of the life cycle components and its cumulative effects. This must be done to ensure that there is a clear understanding of technology performance within one specific STBS but also how the technology performed in the different STBS as it was investigated along the value chain. This can take the form of a mathematical standardisation such as a simple numerical ranking or a rationalised weighting system. Making use of ranking is preferred due to the rapid intent of the initial framework, which aims to communicate this standardisation rapidly to stakeholders clearly and attractively by making use of colour to denote performance. The STBS is done without the need for an extensive data mining and analysis process to merely qualitatively identify aspects and factors of importance, which can be further developed in subsequent assessment or modelling process such as a quantitative Multi-Criteria Decision Analysis (MCDA) or the involved process of System Dynamics modelling. This step is further discussed within Chapter 4 as to how the process directly relates to a specific case, which provides insight into considerations for the application process.

Step 4: Strategic Direction and Conclusion Analysis:

The presentation of STBS outcomes to relevant stakeholders is of vital importance. This new impetus, created by the indicated strategic direction, needs to be subscribed to and further investigations can be made in an enlightened and qualified direction. These investigations can include a variety of decision making tools from various bodies of knowledge. Some of the indicated tools, which may follow the STBS, are MCDA studies, LCA decision trees and System Dynamics modelling to add more rigour to the indicated outcomes and strategic conclusions. The most important factor of consideration in the application of further decision tools can be found in the intent and focus of the data and the practitioner. It is of vital importance that sustainability continues to be a high priority. The stated decision tools may not foster sustainability intrinsically if it is not a key directive of the tool and the data used to reach a goal. The STBS tries to position itself as a tool to bridge the gap between these decisions tools, which utilise quantitative data to generate one best scenario and the Framework for Sustainability, which provides a qualitative perspective of the sustainability landscape and which options would occur within the viability envelope. Thus, the STBS attempts to aid in the flow of information from the qualitative sustainability factors into the quantitative assessment and decision tools. This provides the correct inputs to the tools for sustainable outcomes.

Conclusions:

During the evaluation of specific case studies, the scope of the technology assessment will be limited, as only the relevant technologies as per case study will be evaluated as they occur in each component along value chain. It thus becomes very important to ascertain which technologies occur in each specific component in the value chain. This is done to ensure that the relevant technology is assessed in the appropriate STBS containing the correct sustainability criteria. This creates an accurate snapshot picture of technology relevance as depicted by stakeholders. This is then rapidly assimilated by the group due to its effective communication of data and relationships.

3.3.3. Developing the framework:

The final framework for the STBS implementation process (Fig.3.3) included a change to a five Holon representation for sustainability from the three pillar approach as well as the new factors for the STBS to modify the existing TBS. All the initial thinking is described below (Fig. 3.8):

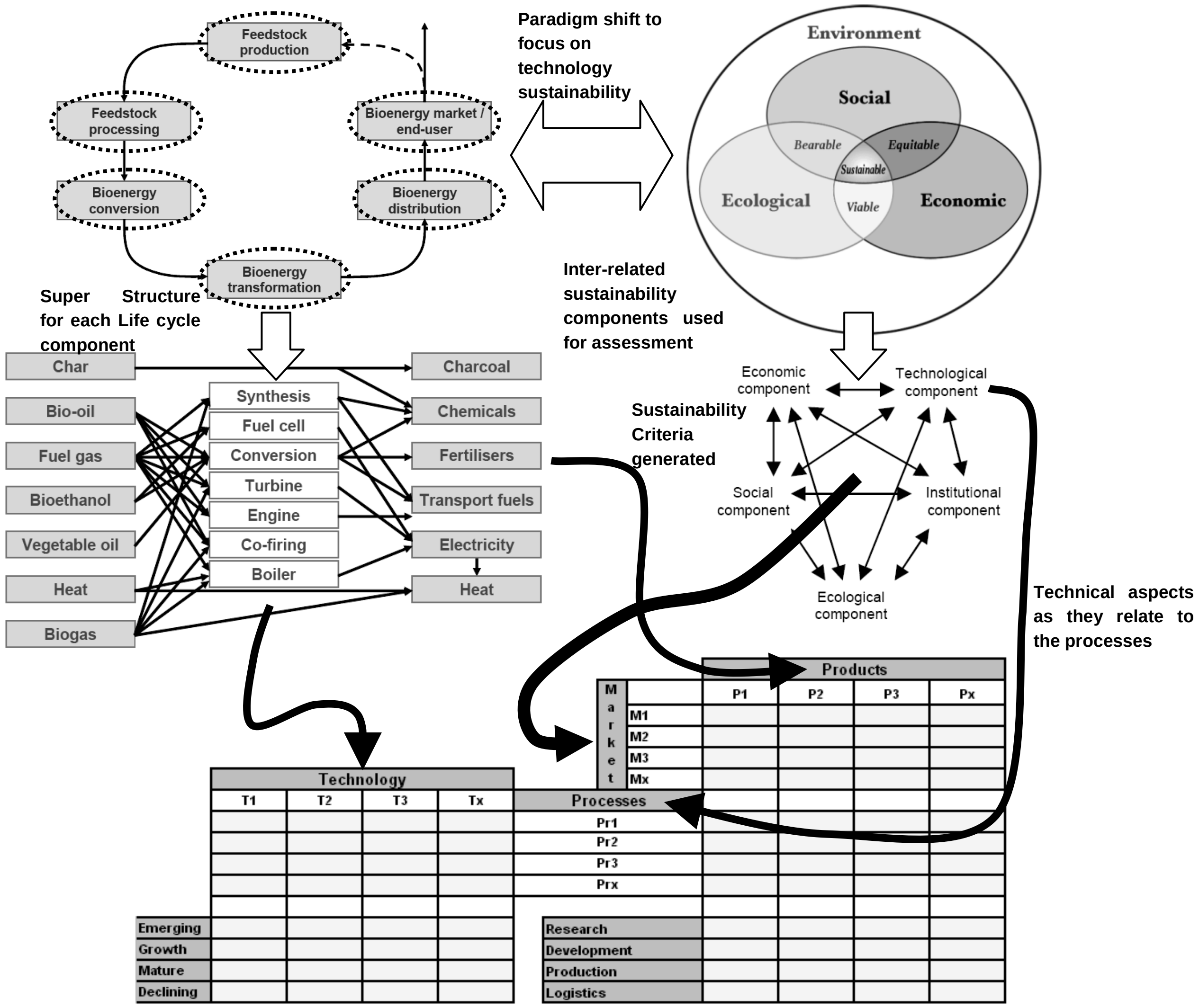

Fig.3.8: The developmental thinking for a sustainable technology balance sheet. This consisted of retaining drivers and establishing new relationships between factors which had to be constantly re-evaluated by reiterative processes to ensure that the logic was retained.

4. Research design and methodology

The following chapter explains the methodologies followed to develop and test the new STBS framework. A general explanation of the intended research strategy is discussed and includes aspects such as which research method will be used, and finally the approach that will be followed in the process to determine the modifications and suggestions for the new STBS framework.

4.1. Introduction

For our research to be deemed credible, the conclusions that we have drawn to be viewed and perceived to be correct and the hypotheses and methodologies proposed to be viewed as robust and a rigorous form of scrutiny is required. A test bed - where the ideologies can be investigated, critically reviewed, revised, and unforeseen pitfalls can be uncovered and suitably corrected- must be created. Scrutinising one's work in this manner is a painful but very necessary process, equal to the tempering of metal, which lends strength and rigour to the newly forged concepts, theories and methodologies, galvanizing these into coherent information from which new knowledge can be generated.

Currently all indicators dictate that the case study approach would be invaluable to the STBS research process. The case study would provide insights into the inner working of the framework's methodologies similarly to the conclusions derived from the informal and formal workshop process. The philosophical approach of learning through the action of doing is deemed to be appropriate and applicable.

4.2. Research strategy

The research strategies include a comprehensive literature review to identify shortcomings within current TA methodologies and to determine useful TA techniques, which can be used to meet the newly defined objectives for a new TA framework. With the action points as guidelines, required factors and criteria can be discussed for the new framework. This discussion is to be done through formal and informal methods. Initially informal interviews and meetings can be held with a diverse group of skilled individuals and knowledgeable experts to facilitate the initial conceptual process and case study investigation, this can then later be ratified during a formal workshop exercise to discuss outcomes and reiteratively further develop the framework. However, in order to test the studies' effectiveness for achieving the objectives of the new framework, the framework will be assessed by its application on real case studies. Conclusions can then be drawn and presented to the focus groups at the workshop, so that further developments and modifications can effectively be added. This feedback exercise is important to gauge the success and usefulness of the STBS as a new TA method (Figure 4.1).

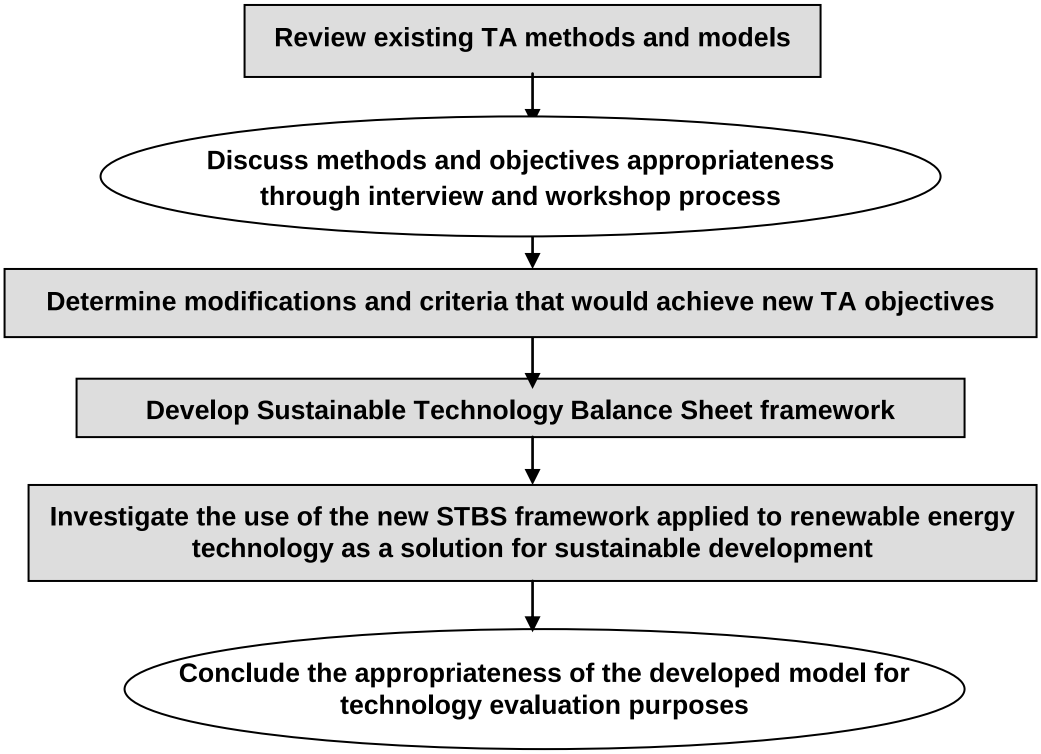

Fig. 4.1: Research strategy.

4.3. Conceptualising the case study approach

A case study approach was used to understand and test the developed Sustainable Technology Balance Sheet (STBS) tool. In order to develop and assess the framework against the objectives, two case studies was conducted. Both studies consisted of tabletop research and paper based reviews of case studies, which have already been concluded, to which the STBS methodology can be applied and the outcomes and conclusions evaluated and compared to provide improvement strategies and areas requiring modification and reworking. One case study was done on renewable energy technology implementation where the project was a failure and the study provides concrete reasons why it was unsuccessful which can be included within the STBS to ascertain whether these recommendations would be helpful in project of this nature in the future. The second study was done on a renewable energy project which is still at an inception and feasibility stage, in fact project feasibility and technology viability forms the cornerstones of this case study. Both these approaches are limited and may be flawed, the first, could be argued that it does not provide adequate feedback for development and may bias the outcomes due to its own conclusions. The second case was severely hampered by a lack of credible information which made technological comparisons very difficult. This was also exacerbated by the project having stalled due to factors including external economic pressures in the form of the international recession and lack of decisive political will. However once the conclusions had been formulated these was presented formally and informally to a diverse group of stakeholders and experts to aid in the developmental process and this was done in a reiterative fashion to provide feedback and methodology evolution as well as instilling a better understanding of the proposed framework amongst all the members of the focus group. All these actions thus lead to the identifying of new meanings, new models, different interpretations, and new solutions to the structure of the proposed framework.

Each of the case studies was ratified by means of meetings / forums / workshops. Interested parties that were invited to attend and participate in the meetings / workshops will include:

- community stakeholders,
- government departments,
- private sector, and
- experts in the form of academics and practitioners

The objective of the forum would be to obtain a representation of a multidisciplinary group of decision-makers that have in-depth knowledge of their respective fields of expertise, but are also familiar with technical issues surrounding RET, TA and sustainable development.

The STBS was firstly discussed informally among a group of experts to generate relevant information and stakeholder identification. These are to be utilised during the development of the tool. These meetings were then become increasingly formal with feedback of developments and obstacles provided to the various experts and stake holders involved as a focus group. Finally, a formal presentation of the proposed STBS tool was made during a workshop to stakeholders including members of DWAF, at which time further inputs were given.

Keeping this in mind, we have gone through a process of conceptualisation of a modified TBS, taking the form of an action type and mixed method research approach to generate constant learning.

Outcomes are to be generated in an organic fashion during the interaction with experts, and during a formal and informal workshop process that reinforces the concept of the higher value of the process followed, as opposed to specific outcomes as we discussed in the TBS. A combined process similar to Technology Roadmapping was followed, together with the TBS framework while always modifying and pausing to align goals, retaining logic, and maintaining a sustainability perspective, which is the key to the modification.

During the various discussions and development processes constant feedback was utilised for the STBS development. This was then finally presented to all of the stakeholders as a final assessment of how well the framework addresses the objectives through the implementation of the action points. The feedback from the Department of Water Affairs and Forestry (DWAF) was of critical concern as they form the major stakeholder or client for the proposed framework within the context of the case study, thus it is critical to understand whether the framework meets the needs of DWAF as a policy maker involved in an industrial project in the form of the PPP.

4.4. Critical analysis of the proposed research methodology:

For the Case Study method, one generally utilises one or a few of units of analysis. However, for high validity case study research one is required to utilise multiple sources of evidence, which is collected and analysed. Thus in an effort to improve this various sources of information were accessed including; documentation, archival records, interviews, direct observations and participant-observations. Fact-finding conducted within an organisation or amongst a group with common agendas and like-minded backgrounds can lead to bias and should be viewed as one source of evidence, no matter how many respondents you have.

Perhaps the greatest flaw within the case study approach is the lack of rigor. This can be induced specifically by perceived and unwanted bias along with other uncertainties derived from drivers such as hidden agendas towards sinister goals. This forms the greatest concern for the investigator to guard against. The second concern faced during the case study is how to prove generalisation which can only be achieved through the replication of the study within multiple investigations. It is however the aim to provide a method which is generally applicable and not the generalisation of outcomes (Yin, 1994).

The case study approach has also been widely criticised for being a cumbersome method making use of too many resources to produce massive, unreadable documents. This can however be easily avoided by limiting the writing style to focus on matters which are of critical importance to the study and to conduct efficient collections of valuable information (Yin, 1994).

The perceived benefits of the case study approach for this study pertains to the investigation of contemporary phenomena within a real life context thus providing understanding of a specific instance as well as laying the foundation for generalisation (Yin, 1994). This said the generalisation process is not an easy one and will require further research to increase the sources of evidence and investigation including rigorous discussions with experts in the form of interviews or surveys as well as further extensive case study application and research.

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5. Results

5.1. The thinking around the technology factor:

Utilising both the case study and action research approach much of the initial development was done through initial trial and error. Followed by a process of discussion and reiteration with experts, furthered my own understanding as well as developed my own opinions on which solution should be pursued.

A clear theme started to emerge from expert discussions and quite clearly from literature. The review of literature indicated that there were three specific strategies, which could be pursued in the modification of an existing framework. Firstly, one could integrate sustainability holons into the existing four factors of the TBS while retaining the structure and logic. Secondly, additional sustainability factors could be added to the TBS and the framework extended and new logic created to rationalise the modification. Thirdly, a specific sustainability TBS to be referred to as the STBS could be formulated with various implications to the development of new factors and structure or the retention of logic (Figge *et al.,* 2002).

A top down approach was taken from the beginning to focus on the specific technologies, which are to be assessed, as this was preferred for the case studies. In most instances, the various stakeholders would dictate the relevant technologies relative to the investigated case and in this investigation's second case study, a tender process. This could include technologies deemed to be of importance to a specific energy system, such as gasification, combustion and pyrolysis technologies to convert biomass to energy.

One of the major challenges when looking at technologies is the large number of diverse sub-technologies of which they are made. This presented the question as to what would be the best approach to assess the technology holistically in an ordered fashion.

A solution that came to mind is that of a systems approach and to keep a systems point of view. A second solution was discovered during the Process factor discussion, namely a Life Cycle approach that provides a look at the life span of a technology or product to indicate hidden pitfalls, which may only become apparent later in a project.

Due to the scope and resource limitations, this study looks only at the specific technologies described by Stakeholder engagement.

During the discussion and informal workshop process it became clear that it was not easy to address sustainability within the predefined factors as the focus of these factors were limited to supply and demand economic perspectives. For example, at the technology level, it may be as critical to unpack the different technologies to ensure a holistic view and there would be opportunities to assess sustainability later within the framework.

5.2. The thinking around the process/capabilities:

During the discussions that generated understanding of the various processes required or imparted by a specific technology, it became very apparent how the process factor lends itself to life cycle thinking and is thus a prime area to create linkages to sustainability from the technology.

Firstly, it became apparent that unpacking the technological processes along the value chain would generate vast insight into the impacts of the technology as one progress along the value chain factors. These factors also provide general sub-groups within the process factor under which different technologies can be identified and assessed.

Once the value chain thinking was discovered as a possible means of aiding the systems thinking, various practical solutions were discussed. These include looking at only one position on the value chain at a time and generating a STBS for each position individually thus clearly highlighting specific impacts between different technologies.

This was done because each part of the value chain would have specific sustainability criteria as each part has different stakeholders with unique requirements (Figure 5.1).

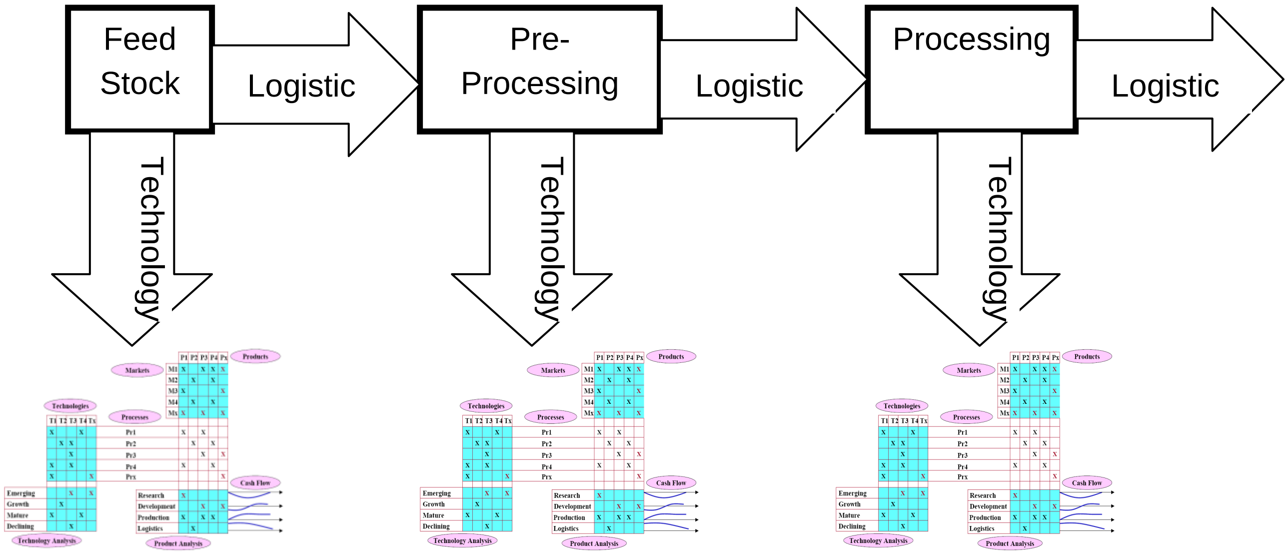

Fig.5.1: The addition of life cycle thinking to the TBS providing the bases for a new tool.

As the framework synthesis process started, it became apparent that of the three modification strategies toward sustainability, one had to be singled out and developed further. The one that would be perused should add the maximum value to the current TBS by including life cycle thinking and sustainability science. A trade-off analysis was required for the various strategies and this was done in a pragmatic way through general consensus within the expert group:

- Replacing existing factors or criteria with new factors relating to sustainability while retaining the original structure and relationships.
- Modifying the structure to include an add-on to the framework in which sustainability may be addressed while retaining the original functionality and factors of the framework intact.
- Retaining the original framework in it's entirety but shifting the focus of the framework to meet new needs.

The latter was the approach, which organically presented itself during the initial discussions. The original TBS did meet the requirement of the TA but was lacking in specific areas such as sustainability, which was felt could be overcome by a simple paradigm shift. This could be done by modifying the outcomes though the manipulation of the inputs by changing the user's point of view to meet new sustainability goals and criteria. This change in the frame of reference should be carried throughout the framework and distribute the thinking into all the various factors if possible. These new inputs will have the desired impacts on the outputs thus retaining some of the original framework's intents while producing a completely new set of outcomes, which are in line with sustainability. This can be clearly seen when one takes the pull force or driver, created by the market factor, and one modifies its requirement to align with sustainability sciences. This can be done by no longer having a market requiring a specific product but one, which demands a specific sustainability aspect or criteria. For example, markets demand for high fuel efficiency or low waste production.

The aspect of life cycle thinking also emerged during the research and it was highlighted that this would add value to the TBS as the process of following the life cycle value chain provides an ordered look at the various technology subsets and how they may impact on the overall performance of the system. This approach also aids in the technology assessment by identifying technologies, which may have been overlooked otherwise and thus improving on the rigorousness of the TBS.

5.3. The case studies:

As with all case study research, one believes that finding the most suitable case study is critical for the success of the research, which to some extent may have merit in regards to the requirements of the research as well as the availability of buy in and data within the case. The perfect fit is however, less critical to the process of developing the STBS because the lack of fit may contribute more to the understanding of the flexibility and duplicity required from the STBS in unique real world situations. The STBS was therefore exposed to differing environments, which required specific methodological and structural modifications that were believed to be required to add value to a technological environment and process.

The two proposed case studies available to evaluate the STBS framework were the Lucingweni mini-grid investigation and the Working for Energy proposals. Each will require a brief discussion to highlight the STBS contribution.

5.4. Lucingweni mini grid case study:

The first case study is a small investigation making use of a case study report, which was created for the development of frameworks and methodologies. This information was taken from the report: Performance measurement of renewable energy technology using sustainability science: Lucingweni mini-grid (Brent and Rogers, 2009) which had already been finalised and within the public domain.

The case investigates the effects of renewable energies on the sustainability of a rural community. The energy technologies came in the form of Solar Photo-voltaic and Wind turbine technologies that feed into a mini-grid system through controllers, inverters and battery storage. The energy technologies provided low capacity electricity to a part of the Lucingweni rural community and the sustainability of the system was then evaluated by the application of sustainability science principles.

This evaluation was deemed appropriate as an initial case study and was chosen due to its simplicity and ease. Most of the relevant data was available and generated through similar processes as required by the STBS. The mini-grid case is also very simple due to the very short technology value chain and the narrow focus offered by the system boundaries.

The original report highlighted information considered important by the relevant stakeholders through the engagement process. Specific data relating to key aspects by which the project should be evaluated are clearly stated and the STBS was used in such a manner to retain specifically its integrity and value.

These aspects related to factors required by the STBS and addressed by the report include: the sustainability criteria used to evaluate the sustainable nature of the project, the technical specifications relating to the specific technologies and the technologies of various configurations compared with status quo energy technologies which are available. The STBS was thus suitably modified to accommodate the specific *nuances* required by this case.

5.4.1. The technical aspects:

If one follows the process as described by the STBS conceptual framework in the preceding chapters, one is faced with a decision of where to start. Be it at the technology system interface, identifying the relevant technologies and population - the technology value chain - or alternatively do we start at the market or demand area, which includes the stakeholder needs' analysis and the creation of sustainability criteria.

The approach can be discussed with the stakeholders and can be influenced according to the various visions and requirements or specific agendas or aims. For the Mini-grid case, this discussion is moot as both technology push and market pull drivers had already been clearly addressed if not identified as such in the original investigation report.

If one looks towards the technology value chain, it becomes apparent from the report that the value chain is limited to the production component of the generic energy value chain. The limitation is primarily due to the system boundaries imposed by the report scope to which we also adhered to for the STBS boundaries, as was the perceived wishes of the stakeholders. Thus, the only technologies focused on were those, which had a direct impact on the generation of energy, in this case electricity. The system is explained by figure 5.2.

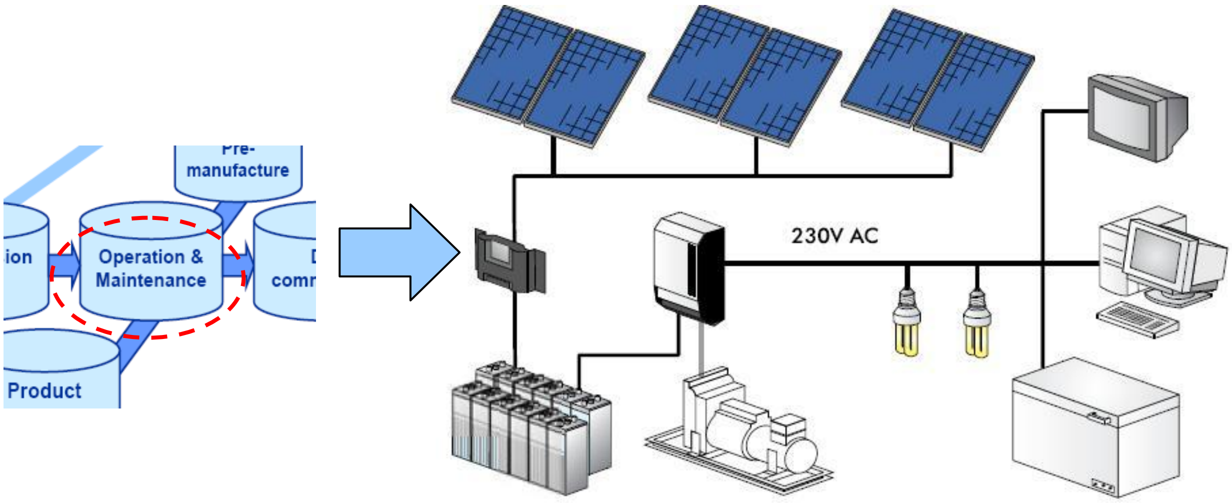

Fig. 5.2: The mini-grid consists of renewable energy technologies such as solar photo-voltaic and wind turbines regulated by controllers, inverters and battery storage, which provided low capacity electricity to specific members of the Lucingweni rural community

The specific technologies as well as the relevant technical details used during the evaluation are found in tables 5.1 and are used to populate the Technological Process vs.Technical Aspects and specifications matrix.

Table 5.1: Include all relevant technical considerations

Comparison of costs Shell and three diesel mini grid configurations with ESKOM line extension (discounted to Rand 2003 values)

	Shell System					Diesel Generation			Eskom Power
Item	Wind	PV	Batteries and power conditioner	Mini-Grid, invertor, and controller	**Total**	**Shell Mini Grid, batteries**	**Shell Mini Grid and Shell controller**	**Eskom Mini Grid and ESKOM controller**	**National Grid extended 13 km**
Capacity kW p	36	54	75	75	75	75	75	75	5000
Installation cost/R	1,108,175	2,661,850	2,207,186	3,705,210	9,682,421	6,088,920	3,904,721	705,000	1,272,103
Installation cost R/kWp	30,783	49,294	29,326	49,229	158,631	81,186	52,063	9,400	254
equipment operation/supervision costs pa	14,177	34,054	28,237	47,402	123,870	123,870	89,871	50,209	16,274
routine service pa	8,658	20,797	17,245	28,949	75,649	67,428	50,184	26,743	9,939
depreciation/capital replacement pa	55,409	133,093	220,719	185,261	594,480	445,881	225,163	75,152	63,605
Diesel cost	-	-	-	-	-	-	185,267	185,267	-
Sum of costs R pa (Sum d+e+f)	**78,244**	**187,943**	**266,200**	**261,611**	**793,999**	**637,179**	**550,484**	**337,372**	**89,818**
System losses (% power generated)	est <1%	est <1%	19.00%	13.00%	32.00%	18.00%	est <1%	est <1%	est <1%
Scheduled Service (% time)	97.00%	97.00%	97.00%	97.00%	97.00%	97.00%	97.00%	97.00%	97.00%
Capacity for generation (% time)	25.00%	15.00%	100%	100%	100%	> 95%	> 95%	> 95%	100%
kW AC hr/an	52,237	47,013	99,250	99,250	99,250	99,250	99,250	99,250	99,250
kW AC cont	6	5	11	11	11	11	11	11	11
R/ kW AC hr (divide h/l)	**1.5**	**4**	**2.68**	**2.64**	**8**	**6.42**	**5.55**	**3.4**	**0.9**
Ranking for lowest cost					**5**	**4**	**3**	**2**	**1**
Times more expensive than Municipal charge of Februrary 2007 (Divide n/ R 0.30 kWhr)					2607%	2092%	1808%	1108%	295%
Comparison with CSIR report 2004 R/kWhr	0.57	2.2	n.a.	n.a.	n.a.	n.a.	n.a.	2.7	0.297

All of the tables used from the original Lucingweni report contained quantitative data and a high level of data for each of the relative technological specification compared to the specific technologies. The data in these tables was collected over a long period of time, making use of rigorous investigations and research to generate the data, which in turn was used to populate the STBS. This data usage indicates the flexibility of the STBS framework, as it is not qualitative which increases the STBS rigour. The STBS goal is not only to be used as a communication tool but also to provide rigorous strategic direction.

The main focus of the STBS is in the generation of factors, which develops the thought processes that was used to evaluate and then contribute to the technologies at a high level by providing direction to further research to find quantitative data and generate more rigorous models such as the MCDA. As can be seen in tables 5.2a & 5.2b are simple matrices, which have been populated by making use of the data of table 5.1 in a more simplified form. This simple matrix shown below is a simple performance ranking number system that uses a colour coding system to indicate the performance to non-technical individuals, red being least sustainable and green most. Any quantitative or qualitative means may be used according to the requirements of the stakeholders involved.

Table 5.2 a.: Initial ranking matrix may be adequate.

Technological Processes									
1.Proven wind turbines	2.Shell solar PV	3.Mini-Grid, invertor and controller	4.Batteries and power conditioner	5.Total Shell System	6.Generator (D),Shell Mini Grid, batteries	7.Generator (D),Shell Mini Grid and Shell controller	8.Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Power National Grid extended 13 km	Technical aspects and requirements
2	2	3	3	3	3	3	3	5	Capacity kW p
4	3	3	2	1	2	3	5	4	Installation cost/R
3	2	3	2	1	2	2	4	5	Installation cost R/kWp
3	2	3	2	2	2	2	4	5	equipment operation/supervision costs pa
3	2	3	2	2	2	2	4	5	routine service pa
3	2	2	2	1	1	2	4	5	depreciation/capital replacement pa
5	5	2	3	2	3	5	5	5	System losses (% power generated)
4	4	4	4	4	4	4	4	4	Scheduled Service (% time)
3	2	4	4	4	4	4	4	4	Capacity for generation (% time)
5	3	4	4	1	2	3	4	5	R/ kW AC hr (divide h/l)
3.5	2.7	3.1	2.8	2.1	2.5	3	4.1	4.7	

Table 5.2 b.: The ranking system augmented by a colour coding system makes for a more effective communication tool for non-technical stakeholders.

Technological Processes									
1.Proven wind turbines	2.Shell solar PV	3.Mini-Grid, invertor and controller	4.Batteries and power conditioner	5.Total Shell System	6.Generator (D),Shell Mini Grid, batteries	7.Generator (D),Shell Mini Grid and Shell controller	8.Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Power National Grid extended 13 km	Technical aspects and requirements
2	2	3	3	3	3	3	3	5	Capacity kW p
4	3	3	2	1	2	3	5	4	Installation cost/R
3	2	3	2	1	2	2	4	5	Installation cost R/kWp
3	2	3	2	2	2	2	4	5	equipment operation/supervision costs pa
3	2	3	2	2	2	2	4	5	routine service pa
3	2	2	2	1	1	2	4	5	depreciation/capital replacement pa
5	5	2	3	2	3	5	5	5	System losses (% power generated)
4	4	4	4	4	4	4	4	4	Scheduled Service (% time)
3	2	4	4	4	4	4	4	4	Capacity for generation (% time)
5	3	4	4	1	2	3	4	5	R/ kW AC hr (divide h/l)
3.5	2.7	3.1	2.8	2.1	2.5	3	4.1	4.7	

5.4.2. Sustainability criteria:

All projects require site-specific sustainability criteria, which do not however, mean that completely unique criteria had to be devised. The most important process within the STBS is to identify which criteria from the various sustainability criteria models and methodologies, as available from literature, would be suitable and provide value to the project as well as the Lucingweni community.

The generation of sustainability indicators and the consolidation of knowledge created by sustainability thinking was found to have followed two alternative approaches namely, the consensus and the rational approaches (Brent and Rogers, 2009).

The latter was found most popular in the lead technical organisations.

It is generally accepted that it would be very difficult to prepare one rational framework for the numerous developing countries that have limited interpretational and measurements expertise, and a wide range of ecological systems (UNEP, 1999).

The starting point for knowledge on sustainability is the consensus on knowledge and scientific principles contained in literature like the Brundtland report (WCED,1987).

One very important consideration highlighted by the case study, was distinguishing between inductive and deductive reasoning (Brent and Rogers, 2009).

Inductive reasoning is based on the researched case study. This allows for the systematic accumulation of knowledge for contexts where there is no well-tested rational framework available.

This is in contrast to deductive reasoning where knowledge is collected within the scientific principles and the operations of fundamental laws in each discipline. The areas that have been selected for sustainability research on energy technology are: physics, chemistry, and engineering; economy; ecology; society; law/government. The unifying problem is energy and climate change, which provides proof of the multidisciplinary nature of the case.

One of the most important sustainability criteria models developed is the Millennium Development Goals (MDG), which is subscribed to by sufficient amounts of international governing and development bodies to make it one of the models which is mostly above reproach.

See Appendix A.1 for further information of the development of criteria.

Table 5.3 highlights what the specific requirements of the mini-grid electricity are which were used to develop a brief needs analysis required for the STBS matrix.

It does however become clear from the report document conclusions that an inadequate needs analysis was done at the design phase of the project. These inadequacies were addressed by the report and related specifically to the lack of sustainability thinking, especially in regards to the resilience and complexity of the social and technical system. One specific aspect of resilience was seen when the system (The entire case study) was placed into action. It provided the required electricity as described by the need analysis within the technical constraints but as these needs were fulfilled, the social need expanded and the expectation of the community on the product provided by the mini-grid increased. The system could not meet these new social requirements due to the technical constraint that lead to its failure. The failure of the system was indicative of a limited technical resilience or at least a limited awareness of resilience between the two social and technological systems.

Table 5.3: Mini grid system specifications

Category and sub-category of power applications		Unit power	Duration			Sum per category	
	No	AC W	hrs	AC kWh/day	DC kWh/day	AC kWh/day	DC kWh/day
Houses	220						
lights	4	15	4	52.8	62		
radio	1	10	10	22	26		
TV	1	70	5	77	91		
Decoders	1	40	5	44	52		
Cell charger	1	10	2	4.4	5	200.2	235.5
Street lights	70	26	7	12.74	15	12.7	15
Community centre	1	100	10	1	1.18		
lights	10	15	8	1.2	1.41		
telecom	3	40	5	0.6	0.71		
plugs	10	200	8	16	19	18.8	22.1
Drinking water							
pumping	3	2000	5	30	35	30	35.3
Power Generator System							
logger	1	20	1	0.02	0		
telecom	1	10	1	0.01	0.01		
lights	3	45	1	0.135	0.16		
security	1	10	24	0.24	0.28	0.4	0.5
Shops	4						
lights	8	15	10	1.2	1.41		
refrigeration	4	100	8	3.2	3.76	4.4	5.2
Total				266.5	313.6	266.5	313.6
net efficiency	**0.85**						
Inverter efficiency	0.9			11.10604	kW AC cont		

This was then modified and used to populate the originally called Market versus Product matrix, which we can call the Sustainability Criteria versus Product

Requirement and Specification matrix within the STBS. Even with a very case specific modification of this section of the STBS the effects of the factors within the matrix still retains the original relationship between these factors. The factors include that of satisfying market demand or market pull with a specific product or product system devised from the technology and the required technical system we are investigating.

Table 5.4: Initial Sustainability Criteria versus Product Requirement matrix

		Product specification							
Sustainability Criteria		Expected outcomes for Shell Mini-grid: Low capacity electricity produced from renewable resources	Actual outcomes as asses at the end of case study	Supply and Requirement : Homes	Supply and Requirement : Street Lights	Supply and Requirement : Community Center	Supply and Requirement : Drinking Water	Supply and Requirement : Power Generator System	Supply and Requirement: Shops
	Purchase Power Parity (PPP)	2	1			x	x		x
	Gini coefficient	2	1			x	x		x
	Health	2	1			x	x		x
	Education	3	1	x		x			x
	Access to basic services	4	1	x		x	x	x	x
	Positive return on energy investments	3	1					x	
	Affordability of energy	1	1					x	
	Allocation & control of resources	1	1						x
	Legal protection for controls	1	1						
	Access to credit	1	1						x
	Post Kyoto CO2 eq. targets	3	1	x	x	x	x		
	Access to basic resources	4	1	x	x	x	x		x
	Biological community diversity	1	1					x	x
	Soil type maintenance (fertility)	1	1					x	x
	Availability of energy resource	3	1	x	x			x	x
	Jobs (ability to get food)	1	1						x
	Nutrition	1	1				x		x
	Life expectancy	1	1		x		x		x
	Literacy	3	1	x		x			x
	Increased productivity	2	1				x	x	x
	Total	1.9	1						

It was felt that this matrix did not address the comparison of the various technologies by means of the different products adequately. Thus, this matrix was expanded to include similar products, which were generated in different ways with different processes, attesting to the flexibility of the framework.

Table 5.5: Holistic Sustainability Criteria versus Product Requirement matrix:

Sustainability Criteria	Product Specification and Requirements											
	Expected outcomes for Shell Mini-grid: Low capacity electricity produced from renewable resources	Actual outcomes as asses at the end of case study	6.Generator (D),Shell Mini Grid, batteries	7.Generator (D),Shell Mini Grid and Shell controller	8.Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Power National Grid extended 13 km	Specific Electrical Supply and Requirement : Homes	Specific Electrical Supply and Requirement : Street Lights	Specific Electrical Supply and Requirement : Community Center	Specific Electrical Supply and Requirement : Drinking Water	Specific Electrical Supply and Requirement : Power Generator System	Specific Electrical Supply and Requirement : Shops
Purchase Power Parity (PPP)	2	1	2	2	2	4			x	x		x
Gini coefficient	2	1	3	3	3	3			x	x		x
Health	2	1	3	3	3	5			x	x		x
Education	3	1	3	3	3	4	x		x			x
Access to basic services	4	1	4	4	5	5	x		x	x	x	x
Positive return on energy investments	3	1	3	4	4	5					x	
Affordability of energy	1	1	2	3	4	5					x	
Allocation & control of resources	1	1	2	2	4	4						x
Legal protection for controls	1	1	2	2	2	4						
Access to credit	1	1	1	1	1	3						x
Post Kyoto CO2 eq. targets	3	1	1	1	1	1	x	x	x	x		
Access to basic resources	4	1	2	3	4	5	x	x	x	x		x
Biological community diversity	1	1	1	1	1	1					x	x
Soil type maintenance (fertility)	1	1	1	1	1	1					x	x
Availability of energy resource	3	1	2	3	4	5	x	x			x	x
Jobs (ability to get food)	1	1	2	2	2	1						x
Nutrition	1	1	1	1	1	1				x		x
Life expectancy	1	1	1	1	1	2		x		x		x
Literacy	3	1	3	3	3	3	x		x			x
Increased productivity	2	1	3	3	3	4				x	x	x
Total	1.9	1	2.1	2.3	2.6	3.3						

There was however a problem, which occurred due to the modification of the original Technology Balance Sheet. It was felt that a disconnection of the original relationship had occurred within the Process vs. Product matrix. This information is referred to in the STBS as the Technical Specifications vs. Product Requirements and Specification. As one can see both of the factors do not relate to each other but both relate directly to the Technological Process factor within the STBS. If one considers the flow or driving forces in the original Technology Balance sheet and compared it to this disconnection phenomenon it becomes clear that the decision to move the modified Process factor into the original position of the Technology factor, as per the original STBS situated at the left extremity of the framework, catalysed this problem. If the modified Process factor is returned to the central position, it acts as a linkage factor rejoining the connection between the Technical and Product factors. These two factors can be seen as two sides of the Process factor coin, with the Technical factor flowing from the technology push driver into the Process factor and the Product factor flowing from the market pull driving force out of this Process factor. This breakdown in the relationship occurred because of the modified focus or mindset used to generate the STBS but if one realigns the underlying driving forces one can easily restore the relationships. Table 5.6 below indicates this disconnection but it can still be modified within this state to communicate vital information.

Table 5.6: Technical Specifications vs. Product Requirements matrix

Technical Aspects and Specifications	Product Specification and Requirements											
Capacity kW p	Too Low	Too Low	Low	Low	Low	High	Too Low	Too Low	Too Low	Too Low	Too Low	Too Low
Installation cost/R	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
Installation cost R/kWp	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
equipment operation/supervision costs pa	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
routine service pa	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
depreciation/capital replacement pa	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
System losses (% power generated)	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
Scheduled Service (% time)	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
Capacity for generation (% time)	Too Low	Too Low	High	High	High	High	Too Low	Too Low	Too Low	Too Low	Too Low	Too Low
R/ kW AC hr (divide h/l)	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High

These matrices are then collated to produce the Sustainable Technology Balance Sheet in Table 5.7.

Table 5.7: The Lucingweni mini grid Sustainable Technology Balance Sheet

	Product Specification and Requirements											
Sustainability Criteria	Expected outcomes for Shell Mini-grid: Low capacity electricity produced from renewable resources	Actual outcomes as asses at the end of case study	6.Generator (D),Shell Mini Grid, batteries	7.Generator (D),Shell Mini Grid and Shell controller	8.Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Power National Grid extended 13 km	Specific Electrical Supply and Requirement : Homes	Specific Electrical Supply and Requirement : Street Lights	Specific Electrical Supply and Requirement : Community Center	Specific Electrical Supply and Requirement : Drinking Water	Specific Electrical Supply and Requirement : Power Generator System	Specific Electrical Supply and Requirement: Shops
Purchase Power Parity (PPP)	2	1	2	2	2	4			x	x		x
Gini coefficient	2	1	3	3	3	3			x	x		x
Health	2	1	3	3	3	5			x	x		x
Education	3	1	3	3	3	4	x		x			x
Access to basic services	4	1	4	4	5	5	x		x	x	x	x
Positive return on energy investments	3	1	3	4	4	5					x	
Affordability of energy	1	1	2	3	4	5					x	
Allocation & control of resources	1	1	2	2	4	4						x
Legal protection for controls	1	1	2	2	2	4						
Access to credit	1	1	1	1	1	3						x
Post Kyoto CO2 eq. targets	3	1	1	1	1	1	x	x	x	x		
Access to basic resources	4	1	2	3	4	5	x	x	x	x		x
Biological community diversity	1	1	1	1	1	1					x	x
Soil type maintenance (fertility)	1	1	1	1	1	1					x	x
Availability of energy resource	3	1	2	3	4	5	x	x			x	x
Jobs (ability to get food)	1	1	2	2	2	1						x
Nutrition	1	1	1	1	1	1				x		x
Life expectancy	1	1	1	1	1	2		x		x		x
Literacy	3	1	3	3	3	3	x		x			x
Increased productivity	2	1	3	3	3	4				x	x	x
Total	1.9	1	2.1	2.3	2.6	3.3						

Technological Processes										Product Specification and Requirements											
1.Proven wind turbines	2.Shell solar PV	3.Mini-Grid, invertor and controller	4.Batteries and power conditioner	5.Total Shell System	6.Generator (D),Shell Mini Grid, batteries	7.Generator (D),Shell Mini Grid and Shell controller	8.Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Power National Grid extended 13 km	Technical Aspects and Specifications												
2	2	3	3	3	3	3	3	5	Capacity kW p	Too Low	Too Low	Low	Low	Low	High	Too Low	Too Low	Too Low	Too Low	Too Low	Too Low
4	3	3	2	1	2	3	5	4	Installation cost/R	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
3	2	3	2	1	2	2	4	5	Installation cost R/kWp	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
3	2	3	2	2	2	2	4	5	equipment operation/supervision costs pa	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
3	2	3	2	2	2	2	4	5	routine service pa	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
3	2	2	2	1	1	2	4	5	depreciation/capital replacement pa	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
5	5	2	3	2	3	5	5	5	System losses (% power generated)	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
4	4	4	4	4	4	4	4	4	Scheduled Service (% time)	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.	Ave.
3	2	4	4	4	4	4	4	4	Capacity for generation (% time)	Too Low	Too Low	High	High	High	High	Too Low	Too Low	Too Low	Too Low	Too Low	Too Low
5	3	4	4	1	2	3	4	5	R/ kW AC hr (divide h/l)	Too High	Too High	High	High	High	Low	Too High	Too High	Too High	Too High	Too High	Too High
3.5	2.7	3.1	2.8	2.1	2.5	3	4.1	4.7													

During this modification and development process of the STBS it became apparent that the original logic of the TBS was lost or badly impacted on; specifically in regards to the underlying driving forces and how these affect the relationship between the four factors.

In an attempt to counteract the breakdown of the flow created by the driving forces, as found within the original STBS, further modifications were made to restore those relationships and retain the desired interactions between the factors of the STBS.

This breakdown became very apparent in Table 5.7, as the Technical Aspect factor has absolutely no relevance or relationship to the Product Requirement factor to which it is being compared.

This occurred primarily due to the modification of the individual matrices that ultimately influenced the flow and logic of the STBS as a unified assessment framework.

A simple solution was developed to modify the flow of factors further by moving the Technological Process factor into the central slot on the STBS between the Technical Specification factor and the Product Requirement factor. Movement of one factor created the required linkage between all the factors and in effect reinstated the original logic and underlying driving forces associated with the original TBS. This structural move has galvanised the STBS as a conceptual framework.

The only weak link within the STBS was still found at the interface of the Product Requirement factor and the Sustainability Criteria.

A rationale had to be developed which could logically create and bolster the linkage between these two factors.

A relationship between them does exist but it is the close relationship found between the Technologies, the Processes and the Products that drew attention first.

These factors are inseparable as they are integral to the existence of each other and contain the same driving forces as described by the TBS.

It was thus found no longer necessary to separate Technology, Process and Product but merely to focus on the individual aspects pertaining to each other as it becomes necessary to do so. This achieves the goal of assessing each of these factors for sustainability by relating the Technology, Process and Products to the Sustainability Criteria simultaneously and by retaining their intrinsic relationships which has an impact on the overall sustainability in its own right.

Table 5.8: The various matrices integrated to form the initial STBS

This linkage was further investigated within the second case study: The IAP project

Sustainability Criteria	Expected outcomes for Shell Mini-grid: Low capacity electricity produced from renewable resources	Actual outcomes as asses at the end of case study	6.Generator (D),Shell Mini Grid, batteries	7.Generator (D),Shell Mini Grid and Shell controller	8.Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Power National Grid extended 13 km	Specific Electrical Supply and Requirement : Homes	Specific Electrical Supply and Requirement : Street Lights	Specific Electrical Supply and Requirement : Community Center	Specific Electrical Supply and Requirement : Drinking Water	Specific Electrical Supply and Requirement : Power Generator System	Specific Electrical Supply and Requirement : Shops
Purchase Power Parity (PPP)	2	1	2	2	2	4			x	x		x
Gini coefficient	2	1	3	3	3	3			x	x		x
Health	2	1	3	3	3	5			x	x		x
Education	3	1	3	3	3	4	x		x			x
Access to basic services	4	1	4	4	5	5	x		x	x	x	x
Positive return on energy investments	3	1	3	4	4	5					x	
Affordability of energy	1	1	2	3	4	5					x	
Allocation & control of resources	1	1	2	2	4	4						x
Legal protection for controls	1	1	2	2	2	4						
Access to credit	1	1	1	1	1	3						x
Post Kyoto CO2 eq. targets	3	1	1	1	1	1	x	x	x	x		
Access to basic resources	4	1	2	3	4	5	x	x	x	x		x
Biological community diversity	1	1	1	1	1	1					x	x
Soil type maintenance (fertility)	1	1	1	1	1	1					x	x
Availability of energy resource	3	1	2	3	4	5	x	x			x	x
Jobs (ability to get food)	1	1	2	2	2	1						x
Nutrition	1	1	1	1	1	1				x		x
Life expectancy	1	1	1	1	1	2		x		x		x
Literacy	3	1	3	3	3	3	x		x			x
Increased productivity	2	1	3	3	3	4				x	x	x
Total	1.9	.	2.1	2.3	2.6	3.3						

Product Specification and Requirements

Declining	Mature	Growth	Emerging	Capacity kW p	Installation cost/R	Installation cost R/kWp	Equipment operation/supervision costs pa	Routine service pa	Depreciation/capital replacement pa	System losses (% power generated)	Scheduled Service (% time)	Capacity for generation (% time)	R/ kW AC hr (divide h/l)	Total	Technical Aspects and Specifications	Expected outcomes for Shell Mini-grid: Low capacity electricity produced from renewable resources	Actual outcomes as asses at the end of case study	6.Electricity from Generator (D),Shell Mini Grid, batteries	7.Electricity from Generator (D),Shell Mini Grid and Shell controller	8.Electricity from Generator (D),Eskom Mini Grid and ESKOM controller	9.Eskom Electricity National Grid extended 13 km	Specific Electrical Supply and Requirement : Homes =Capacity	Specific Electrical Supply and Requirement : Street Lights = Low Cost per Unit	Specific Electrical Supply and Requirement : Community Center = Instalation Cost	Specific Electrical Supply and Requirement : Drinking Water = System Reliability	Specific Electrical Supply and Requirement : Power Generator System = Equipment operation/ supervision costs pa	Specific Electrical Supply and Requirement : Shops = Depreciation /capital replacement pa
			x	2	4	3	3	3	3	5	4	3	5	3.5	1.Proven wind turbines	x	x					Too Low	Too High	Too High	Low	High	Too High
			x	2	3	2	2	2	2	5	4	2	3	2.7	2.Shell solar PV	x	x					Too Low	Too High	Too High	Low	Ave.	Too High
			x	3	3	3	3	3	2	2	4	4	4	3.1	3.Mini-Grid, invertor and controller	x	x	x	x			Low	Too High	Too High	High	Ave.	Too High
	x	x	x	3	2	2	2	2	2	3	4	4	4	2.8	4.Batteries and power conditioner	x	x	x				Low	Too High	Too High	Ave.	High	Too High
			x	3	1	1	2	2	1	2	4	4	1	2.1	5.Total Shell System	x	x					Low	Too High	Too High	Too Low	Too High	Too High
	x	x		3	2	2	2	2	1	3	4	4	2	2.5	6.Generator (D),Shell Mini Grid, batteries			x				Low	Ave.	Ave.	Ave.	Ave.	Ave.
x	x	x		3	3	2	2	2	2	5	4	4	3	3	7.Generator (D),Shell Mini Grid and Shell controller				x			Low	Ave.	Ave.	Ave.	Ave.	Ave.
x	x	x		3	5	4	4	4	4	5	4	4	4	4.1	8.Generator (D),Eskom Mini Grid and ESKOM controller					x		Low	Ave.	Ave.	Ave.	Low	Ave.
x	x			5	4	5	5	5	5	5	4	4	5	4.7	9.Eskom Power National Grid extended 13 km						x	Very High	Low	Low	Very High	Very Low	Low
Technology S-Curve				Technological Processes																							

	Expected outcomes for Shell Mini-grid	Actual outcomes	6.	7.	8.	9.	Homes	Street Lights	Community Center	Drinking Water	Power Generator System	Shops
Research												
Development	x	x										
Production	x	x	x	x	x							
Logistics												

5.5. Introduction to the Working for Energy case study

Woody biomass has been utilised as a fuel dating back to the beginning of civilisation –indeed the use of fire may have been the most important advance in the history of humans. The utilisation of biomass feedstock for energy production is carbon neutral because the removal of carbon dioxide by the tree during its growth period offsets the generation of CO_2 during its combustion.

In the context of this case study, woody biomass is a waste product of the Working for Water programme. Utilising it as a fuel can thus be seen as a solution to a waste problem as well as contributing to mitigating the energy crisis, without increasing climate change progression, and providing employment and social-economic upliftment.

The Working for Energy (WfE) programme was developed as a "Value Added Industries" (VAI) development project" initiated by the Working for Water programme (WfW) to develop the additional benefits of utilising and extracting biomass. WfW is an expanded public works programme administered by DWAF. WfW was started in 1995 to control Invader Plants in a sustainable manner and to create jobs. More than one billion Rand has been invested in WfW since its inception and currently provides employment opportunities for up to 30 000 people in around 300 clearing projects throughout South Africa.

The utilisation of biomass is expected to create an additional benefit stream for WfW, and concurrently create the opportunity for economic empowerment of historically disadvantaged individuals. This will be achieved through the development of down-stream industries, which will operate either independently, or as partnerships between the public and private sectors. The critical success factors here are, from DWAF's perspective, a viable source of supply and a reliable, economical supply chain, which private parties can exploit under an agreement with DWAF.

The key objectives of WfW are:

- to prevent new and emerging Invader Plant problems;
- to reduce the impact of existing priority Invader Plants;
- to enhance the capacity and commitment to solve Invader Plant problems;
- to provide employment opportunities in the WfW programme;
- to create employment opportunities in the natural resource market; and
- to develop human and social capital.

In addition to these the WfE has three complimentary primary objectives:

- minimising the net cost of clearing Invader Plants;

- maximising economic impacts (e.g. job creation); and
- minimising cleared Biomass to enhance environmental impacts.

The environmental goal of implementing a VAI development project is to reduce cleared biomass to levels comparable with natural conditions. This is done whilst creating an income in order to reduce state expenditure on clearing in-coastal plains and other accessible areas in favour of clearing operations, in areas such as mountains, where it is not economically viable to harvest the biomass.

In March 2001, WfW investigated the possible extension of the VAI development project and found that VAI could have a significant impact in two major areas, namely Small Business Initiatives and the larger so-called Industrial Initiatives. Both could contribute towards job creation, with the Industrial Initiatives promising a substantial impact on the volume of Biomass removed. A further benefit of the jobs that could result from implementation of the Industrial Initiatives project was that they would largely be created in the rural areas of the country.
The Industrial Initiatives products could include bio-fuels, gasses, charcoal products, woodchips, wood/fibre composites, furniture products, organic fertilizer and other products that can be developed from bark and foliage. DWAF believed that there are potential markets, both nationally and internationally, for value-added products, emanating from the further processing of cleared biomass.
WfW seeks to optimise its socio-economic and environmental investment by extracting and utilising biomass resulting from clearing operations. By so doing, both the environmental and sustainable economic benefits of WfW can be further enhanced.

(For more details visit: www.dwaf.gov.za/wfw/)

The removal of cleared biomass, particularly from the Western Cape, Eastern Cape, North West, Northern Cape, Limpopo and Mpumalanga Provinces, has for many reasons become essential. In doing so, the following benefits are derived:

- biological diversity is conserved;
- water security is improved through the enhancement of stream flow and ground water sources;
- ecosystem processes such as the impacts of fires and floods are improved;
- the productive potential of land is restored; and
- the sustainable use of natural resources is promoted.

5.5.1. Sustainability criteria: Working for Energy

The Sustainability Criteria that forms the backbone of the STBS evaluation process was generated by various means. The combination of various sources was thus used to formally establish the relevant sustainability criteria. These sources included the internal working documents of DWAF, which conveyed both the sentiments of the original Working for Water project but also any new requirements of the Working for Energy project. Evaluating these documents for the STBS provided a general better understanding of the relevance or omission of sustainability criteria that ensued. Use was also made of relevant sustainability models, which provided widely accepted and valuable sustainability criteria to augment the original criteria where it was deemed necessary. The most obvious port of call for criteria relating to sustainable development or a project of this nature remains the Millennium Development Goals and the United Nations Environmental Programme's Assessing Biofuels document, which is focused towards sustainable production and utilisation or resources.

There were also other sources used from literature which was deemed relevant and include The Criteria and indicators for bio-energy FBOS document as well as the Sustainability Standards for Bio-energy - WWF document (Öko-Institut, 2006). More information for the development of sustainability criteria for DWAF can be seen in Appendix B.3.

5.5.2. The proposed sustainability criteria for the STBS:

After taking all of the various literature sources into account, a number of informal workshops were held to generate an expert opinion and to test the general consensus among sustainability practitioners. Once this consensus was roughly established the following sustainability criteria was further discussed and generally accepted by all stakeholders including DWAF. DWAF's only interceding comment was that these were not to be viewed as the complete set of criteria but as a baseline to which can be added as the situation dictates.

5.5.3. The technical criteria:

As stated above there were various technical aspects which needed to be addressed within the STBS as they exist in the original DWAF Call for Expression of Intent (EOI) documents and the technologies proposed by these EOI documents (DWAF, 2008). These calls were for specific strategic technologies made by DWAF to facilitate the Value Added Industries development while retaining Sustainable Development goals. These included all the technologies investigated by DWAF within the components along the WfE value chain. These technologies were as specific as the level of evaluation rigor allowed but it was made clear by DWAF that these preferred technologies are not prescribed, and should not limit the proposal of different or novel technologies if such a proposal could be substantiated (DWAF, 2008).

The only shortfall within the technical assessment of the value chain/life cycle is perceived as the Secondary Production component where only two process technologies are discussed, namely Combustion to produce a bio-char product (charcoal) and the Production of wood chips, to be used as either a fertilizer product or as a component product for compaction and further combustion (DWAF, 2008).

It was thus deemed necessary to include a general overview of relevant technologies found within the different components of the established value chain in relation to the prescribed system and its formalised boundaries with specific focus on the Secondary Production value chain component.

A review of relevant technologies enabled the study to focus specifically on Combustion, Slow and Fast Pyrolysis and Gasification. All of which, from a process point, are quite similar and form part of the same process chain, each merely differing at which temperature and at which point in the processing it occurs. The products differ and are produced in the form of renewable liquid, gaseous and solid fuels. Of course Biomass feed stocks and residues can be converted to energy through a large variety of processes including via thermal, biological and physical processes but we have limited our investigation to thermal due to its relevance and the indications generated by the EOI (DWAF, 2008).

Before looking at the specific technologies expressed by the EOI, a general technical overview must be created to aid in the syntheses of technical criteria, which can be used to assess the technologies within the STBS. This can be viewed in Appendix B.1.

5.6. The Invasive Alien Plants STBS:

As we have discussed previously the first step in the STBS process is to investigate the project life cycle so that a generic project value chain can be formulated. In this case, the value chain would initially take the form of a generic energy value chain, which can then be evaluated and expanded to add more specific information pertaining more directly to the specific case under evaluation.

Step one contains two general value chains and are useful in identifying sub-components for the specific value chain and as well as by providing the relevant technologies to be assessed. This is gained from the generation of the Super Structure from the value chain components. This procedure can be called Super Structure synthesis. These value chains are an efficient and fun way to generate system and complexity understanding and to communicate this knowledge easily to non-technical individuals (Figure 5.3 & 5.4).

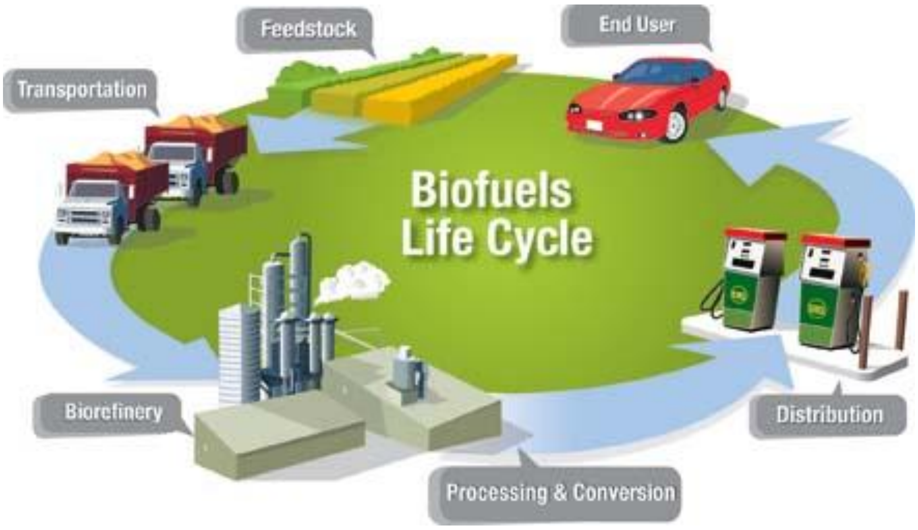

Fig. 5.3: A general energy value chain (Brent, 2008).

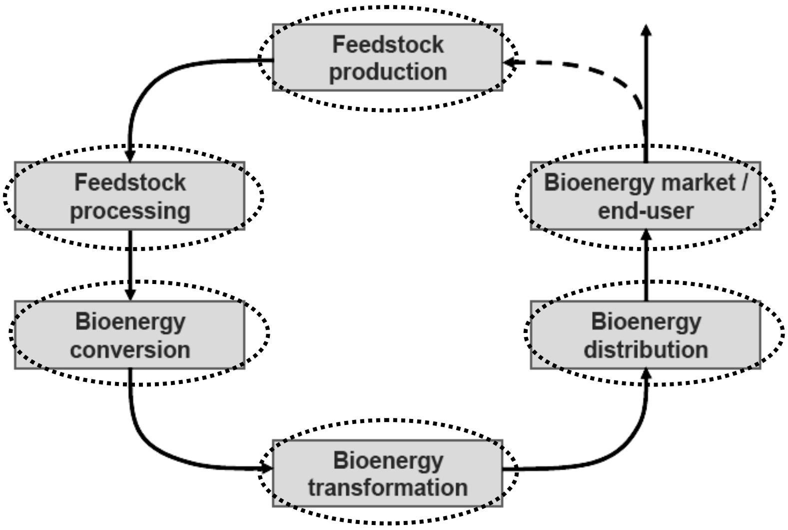

Fig. 5.4: A general bio-energy value chain (Brent, 2008).

From this generic position, it is easy and essential to generate a more specific value chain, which includes more case specific information that fills in the gaps found with a generic value chain. This can easily be generated through the stakeholder engagement process and by expert opinion.

Within the "Call for EOI" document, the WfE group clearly indicated their understanding of the relevant components, which form the project value chain. During the investigation of the information surrounding the WfE value chain, a lack of information pertaining to the Secondary Production component was highlighted and it was found to warrant further investigation. This will provide WfE with insights related to relevant technologies and the factors, which should be considered in a technological evaluation. The STBS was created which specifically focuses on the Secondary Production component. This focus thus extends the value chain component to include the technology of energy production (DWAF, 2008).

The Specific Working for Energy value chain can be generated from Table.5.9:

Table.5.9: Information from which the specific Working for Energy value chain can be generated (DWAF, 2008):

	Element of value chain	**Private Partner/s**	**Status quo**
1	Clearing Cutting down of all Invader Plants Herbicide Treatment Stacking of brush	Managed by the Private Partner/s	Managed by DWAF
2	Biomass preparation Debranching Sorting Bundling Crosscutting Debarking / Piling	Managed by the Private Partner/s	Not currently performed
3	Extraction to roadside ("Harvesting") Carrying ("skidding") Stacking at roadside	Managed by the Private Partner/s	Not currently performed
4	First-haul transportation Loading Transporting Offloading	Managed by the Private Partner/s	Not currently performed
5	Primary Processing i.e. Debarking Crosscutting	Managed by the Private Partner/s	Not currently performed
6	Secondary processing i.e. charcoal / chipping	Managed by the Private Partner/s	Not currently performed
7	Long haul	Managed by the Private Partner/s	Not currently performed
8	Marketing & Sales	Managed by the Private Partner/s	Not currently performed

This information was then used to create the value chain and its components are then used in the subsequent step of the STBS as indicated by the green arrow in figure 5.5 below:

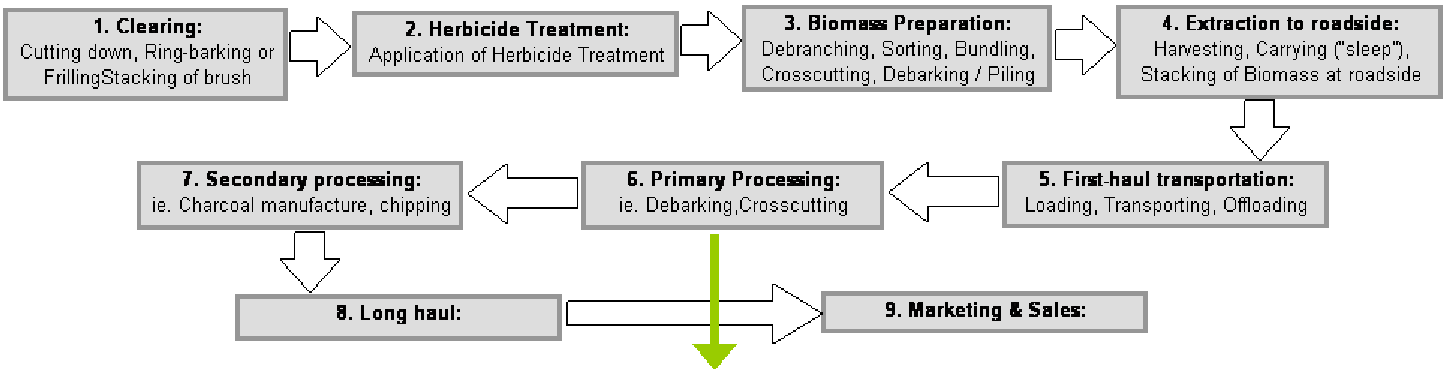

Fig.5.5: The specific Working for Energy value chain (DWAF, 2008)

Once a general consensus has been achieved among the stakeholders and experts, it is possible to move forward to step two of the facilitated process. If, however, a deadlock over issues occur which leads to a stalemate the information from step one can be left incomplete with the premise that it will be reconsidered when relevant information becomes apparent and can be adjusted as the process continues with the subsequent steps in the Implementation process.

The next step, step two in the STBS process, is to generate a Technology Super Structure. This can be achieved in two steps, as a generic structure initially and a secondary case-specific structure containing the technologies which are to be evaluated, as they have been specified and finalised.
Specific emphasis must be placed on identifying the relevant processes, including inputs, processes and outputs, which occur at each value chain component or stage of either products generated or processes required for beneficiation. If during this activity it becomes apparent that products or processes are lacking or have been overlooked due to perceived insignificance then the original value chain must be modified to include these in a new component, which can then be further investigated (Figure 5.6).

The work that has been done by Agama Energy (Gets, 2009) in the generation of an invasive alien plants for renewable energy resource is very comprehensive and appropriate (Figure 5.7). This work contains various super structures generated for specific cases within the bio-energy field and thus make very suitable examples (Gets, 2009).

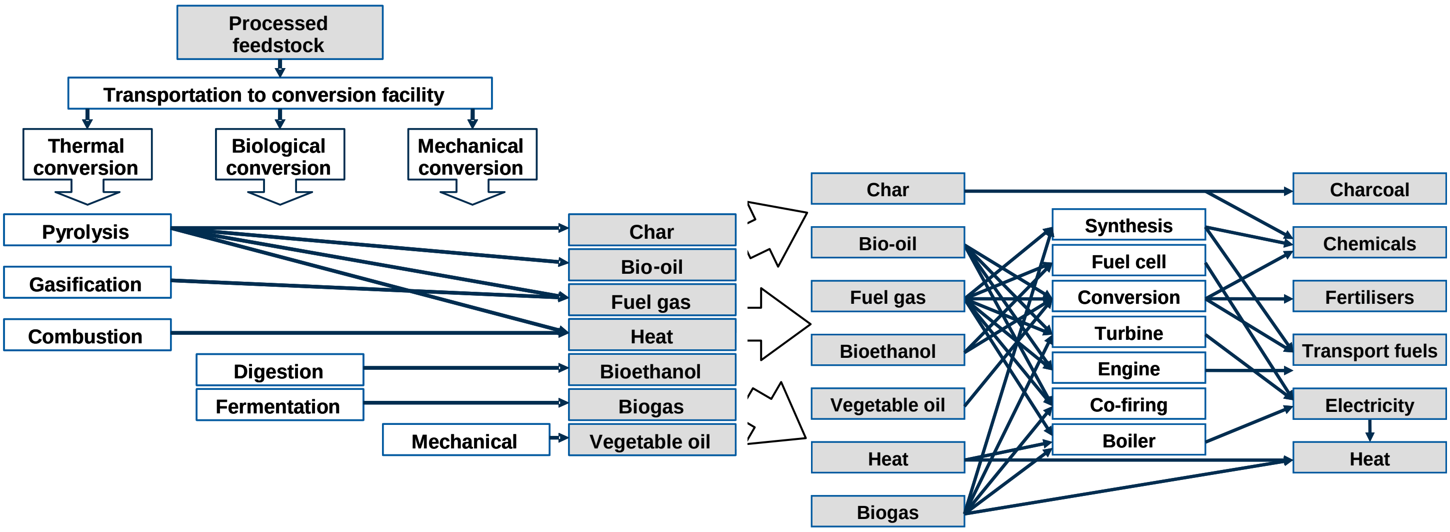

Fig.5.6: Generic energy production super structure for the Primary Energy Conversion component and the Secondary Energy Conversion component (modified from Brent, 2008)

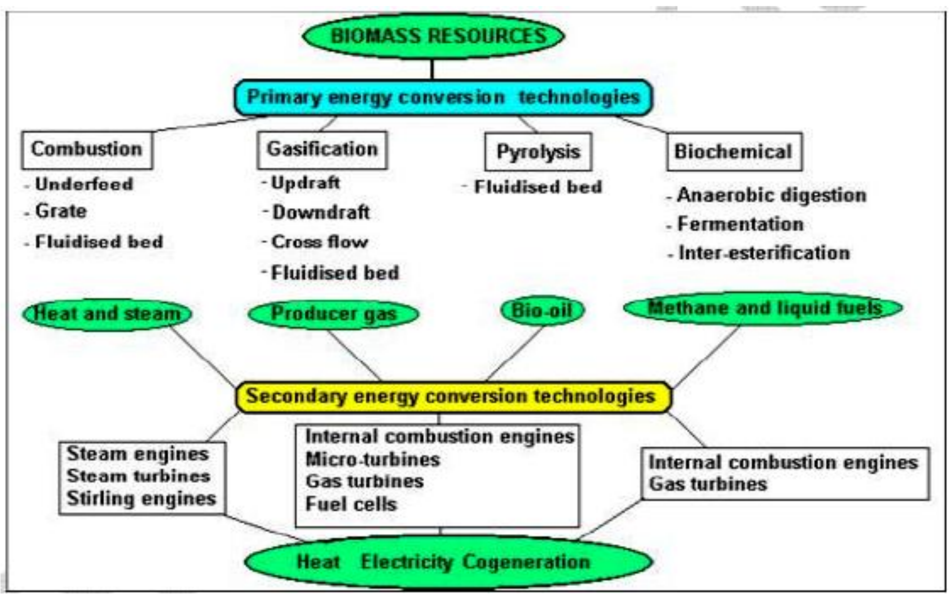

Fig. 5.7: Generic energy production super structure (Gets, 2009).

As indicated previously during the investigation of the WfE case study, the need for a better understanding of the Primary Energy Conversion Component of the value chain was identified and presented an opportunity to assist DWAF in this regard within a very short time frame and with limited resources. The presentation of the perfect test bed to develop and refine the STBS further without the arduous and time consuming task of starting the STBS tool from scratch and without having the inevitable complications associated with expectations which arise from a client with specific agendas and requirements. This freedom allowed the process to flow generically and develop as unbiased as possible. The strong focus on the Primary as well as Secondary Production component was carried throughout the rest of the STBS process and presented by the tables and figures below which are part of step three. These two aspects are very closely related and intrinsically create demands on each other, which influences technical factors for both the processes and the product specification.

Step three can again be summarised as the understanding of the STBS improved with each Implementation Process performed.

As discussed before, the STBS conceptual framework and tool consists of four interrelated factors that influence each other and are compared in three assessment matrices to provide insights to the viability and sustainability of the technologies. Having modified the original Technology Balance Sheet, the STBS communicates factors of sustainability effectively and has improved on a generally accepted methodology by making use of rankings as well as colour coding to intrinsically communicate qualitative and quantitative data accurately to stakeholders.

The four STBS factors are indicated within the various succeeding figures and matrices below which will be discussed briefly:

- **Technological Process** forms the backbone of the technology to be assessed and indicates the conversion process and its intrinsic technology used. These two factors are inseparable and thus assessed as a functional unit. The close linkage between the Technological Process and the products created is also undeniable as the one determines the other, which must thus also remain within consideration. These factors are easily generated by stakeholder engagement and expert opinion, as they are the available processes required to meet the project goals or subsidiary product required by subsequent processes within the value chain components. For the Primary Energy Conversion component four main technological processes were identified primarily due to their proposal by real world entities who will endeavour further with these technologies and secondly, due to the overwhelming relevance of these technologies within literature as well as within the market place. The Technologies proposed were combustion, slow pyrolysis, fast pyrolysis and gasification. All these technologies have been discussed at length.

- **Technical Specifications** are factors used to highlight technical aspects that pertain to the technology for only this specific point in the product life cycle. These are specific technical criteria which are only applicable to a specific value chain component to be included as part of the Sustainability Criteria factors. From a process and operational point of view, these factors are invaluable to more technical stakeholders as they pertain directly to constraints and challenges, which will be faced. These factors include: complexity of operations, feedstock requirement, residence time and capital cost. Some of the Technical Specifications may be very general and may be included within the Sustainability Criteria and this overlap is acceptable as the Technical Specification focuses on the operational aspects of the Technological Process.

- **Product Requirements** creates a linkage between the technological process, and its products and their specifications as required by stakeholders or subsequent processes. This is done to improve the assessment of the technology, as one cannot generate conclusions from the technological process if one does not take aspects and requirements of its products into account. These include the meeting of the stakeholder requirements as well as indicating the various process/product strategies and their affects on sustainability thus the close link between the technology, the process, and the product is required to assess performance in relation to the Sustainability Criteria. In this specific case the Product Requirements are difficult to quantify as most of these products are merely subsidiaries for the following process within the energy value chain and thus do not directly meet the needs of stakeholders. It is, however, imperative that the stakeholders' needs are considered at this stage so that the correct process/product strategies may be implemented at this early stage to ensure customer satisfaction and ultimately ensure a true reflection of sustainability. The process/product strategy becomes especially important when multiple products and undesirable wastes are produced. It is also critical to investigate the concept of product benefit trade-offs, if the product number and specifications can be manipulated by changes the process and technical factors. In the case study example, it was not deemed necessary to investigate all the various process/product strategies nor all of the products, which could be generated by each general Technological Process. The companies proposing the Technological Process in the form of the EOI have already indicated which products they would be pursuing and it was hoped that each company had done some form of feasibility study in regards to the products and technologies which they had proposed. It was then felt that the WfE requirements were merely to assess the sustainability among the EOI and not to engage in an exhaustive study in generating a definite sustainability benchmark, especially as the project is at a relatively early stage and the data can be questioned and verified as the tender process unfolds and the information becomes more apparent.

- **Sustainability Criteria** are generated by stakeholder engagement and by expert opinion to aid the assessment of the technology in terms of it's sustainability. As we have discussed in the preceding sections this factor is of critical importance to the STBS and the Technology Management body of knowledge in addressing sustainability. As can be seen from the matrix, comparing Sustainability Criteria with the Product Requirements (representing the Product/Process/Technology complex) below, much of the functionality and assessment has been taken from the Multi Criteria Decision Analysis (MCDA) methodologies and has been implemented in a simplistic fashion, Along with the understanding that the Sustainability Criteria and outcomes generated are likely to form part of an MCDA study to be done once the initial STBS study is concluded and a strategic direction has been identified. It is thus very important to ensure that there is continuity and consensus between the two methodologies. The synergies between the STBS and the MCDA become quite apparent as the STBS facilitates the initial stages of the MCDA cutting down on the time and engagement required by the MCDA. The STBS as a rapid assessment tool does not replace the MCDA as it focuses heavily on the qualitative data providing a strategic standpoint through the ranking of factors. It can be investigated further by using strong quantitative data to provide rigour to the STBS standpoint and vindicate it's strategic direction or provide further insights which were not possible at the inception of the study. Either way the STBS proves valuable in reducing time and costs of a blind MCDA by providing rapid direction and limiting the possibilities assessed by the MCDA, thus limiting the expense of such a time-consuming study. Another methodology that was also considered was the Life Cycle Analysis (LCA). The LCA is regarded as an excellent tool to further guide decision-makers once the STBS has indicated general strategic directions. The LCA decision trees are invaluable to assess process/product strategies that were initially identified by the STBS and quantified by the MCDA and then synthesised by the LCA.

As stated, previously, the above-mentioned factors are still linked together within the different matrices by logical relationships established between factors by the two underlying forces or drivers, namely the Technology Push and the Market Pull. This drawing power is illustrated by the STBS, present within this case study, created by a market need for sustainability, influencing technology to develop and act as an enabler for sustainability and vice versa as new technology may push sustainability as a driving force modifying requirements and creating new markets.

The three matrices function on an individual and integral level to assess the technologies. The different matrices that form the STBS are:

- The Technological Process vs. Technical Specification Matrix - evaluates the Technological Process using Technical Specifications to indicate the viability of the various projects and technologies (Figure 5.8).

Energy Efficiency	Market Uptake	Immobility	Size capacity	Local Jobs	Lifespan	Energy return on investment	Initial Capital Outlay	Operational Cost	Feedstock Sensitivity	Operational Temperature	Residence Time	Complexity of operations	Flexibility of applications	Relavent Experience	IP ownership	Total	Technological Processes
Technical Aspects and Specifications																	
2	3	3	2	2	2	3	3	4	4	3	2	2	3	2	5	2.813	Slow pyrolysis for charcoal - Silicon Smelters
2	5	1	1	1	2	5	5	3	5	2	1	4	2	3	5	2.938	Combustion plant for electricity - Cape Cleaner Energy (CCE) (CEF and carbon and environmental options
3	3	3	2	2	2	3	3	4	4	3	2	2	3	2	5	2.875	Slow pyrolysis for charcoal and briquettes. (CADAC) - S&P carbon
5	5	2	3	1	2	4	2	2	1	2	3	5	5	3	5	3.125	Gasification for electricity - Umbuso Green power (Technova power systems and CCE)
2	5	1	4	4	2	3	4	4	5	4	1	4	2	5	1	3.188	Combustion
3	4	4	2	3	4	3	4	3	3	3	2	2	3	3	4	3.125	Slow pyrolysis
4	1	2	2	2	4	3	2	2	1	2	5	1	1	2	4	2.375	Fast Pyrolysis
5	4	2	2	2	4	3	2	2	1	1	2	1	4	2	4	2.563	Gasification

Fig. 5.8: The Technological Process vs. Technical Specification Matrix

- The Technical Process vs. Product Requirement Matrix - evaluates the product aspect pertaining to the ability of the process to provide products that can meet the demands of the market (Figure 5.9).

	Product Specification and Requirements											
Technological Processes	Slow pyrolysis for charcoal - Silicon Smelters	Combustion plant for electricity - Cape Cleaner Energy (CCE) (CEF and carbon and environmental options	Slow pyrolysis for charcoal and briquettes. (CADAC) - S&P carbon	Gasification for electricity - Umbuso Green power (Technova power systems and CCE)		Ratio of biomass to products FS:P:W	Specific Energy Supply: Heat	Specific Energy Supply: Steam	Specific Energy Supply: Bio-char	Specific Energy Supply: Bio-Oil	Specific Energy Supply: Gas	Specific Energy Supply: Syngas
Slow pyrolysis for charcoal - Silicon Smelters	X					4:1:1:1:1	Low	Low	High	Ave.	Ave.	Ave.
Combustion plant for electricity - Cape Cleaner Energy (CCE) (CEF and carbon and environmental options		X				2:1:1	High	High	Low	None	Low	none
Slow pyrolysis for charcoal and briquettes. (CADAC) - S&P carbon			X			4:1:1:1:1	Low	Low	High	Ave.	Ave.	Ave.
Gasification for electricity - Umbuso Green power (Technova power systems and CCE)				X		4:3:1	Low	Low	None	None	Very High	Very High
Combustion		X				2:1:1	High	High	High	None	Low	none
Slow pyrolysis	X		X			4:1:1:1:1	Low	Low	Ave.	Ave.	Ave.	Ave.
Fast Pyrolysis						4:2:1:1	Low	Low	Low	High	Low	Low
Gasification				X		4:3:1	Low	Low	None	None	Very High	Very High

Fig. 5.9: The Technical Process vs. Product Requirement Matrix

Note:

The colour coded ranking system indicates desirable sustainability characteristics through a numeric and colour scale with a high sustainability indicated by a comparison ranking of 5 within a green block and a low sustainability indicated by a comparison ranking of 1 within a red block and all subsequent comparison ranks including 4, 3 and 2 indicated by coloured blocks of light green, yellow and orange respectively.

The addition of an X will indicate some form of association between the two indicated factors and provides linkages between matrices

- The Technical Process and Product Requirement vs. Sustainability Criteria Matrix- evaluates the products that are integral to the Technological Process and the Sustainability Criteria pertaining to the sustainability of the Product/Process (Figure 5.10).

Sustainability Criteria	Product Specification and Requirements											
	Charcoal from Slow pyrolysis - Silicon Smelters	Electricity from Combustion plant - Cape Cleaner Energy (CCE) (CEF and carbon and	Charcoal and briquettes from Slow pyrolysis (CADAC) - S&P carbon	Electricity from Gasification Umbuso Green power (Technova power systems and	Weighting per sustainability group	Comments	Specific Energy Supply and Need: Heat	Specific Energy Supply and Need: Steam	Specific Energy Supply and Need: Bio-char	Specific Energy Supply and Need: Bio-Oil	Specific Energy Supply and Need: Gas	Specific Energy Supply and Need: Syngas
Efficiency (1)	2	2	3	5	3					x	x	x
Maturity (2)	3	5	3	5	3		x	x	x			
Modularity (3)	3	1	3	2	3				x			
Size capacity and distribution	2	1	2	3	3				x			
Local capacity (5)	2	1	2	1	3		x	x	x	x	x	x
Lifespan (6)	2	2	2	2	3		x		x			
Product(s) (7)	2	3	2	4	2					x	x	x
Unit cost EROI (8)	3	5	3	4	2						x	x
CAPEX (9)	3	5	3	2	2				x			
OPEX (10)	4	3	4	2	2				x			
Energy balance, EROEI (11)	3	3	3	4	4		x	x			x	x
GHG footprint (12)	4	4	4	4	4		x	x	x	x	x	x
Water footprint (13)	5	3	5	4	4		x	x	x	x	x	x
Biodiversity (14)	5	4	5	4	4		x	x	x	x	x	x
Waste (15)	3	3	3	5	4					x	x	x
Job creation (16)	2	2	2	3	5		x	x	x	x	x	x
Skills development (17)	2	1	2	2	5		x	x	x	x	x	x
Poverty reduction (18)	2	2	2	2	5		x	x	x	x	x	x
Welfare benefits (19)	2	4	2	4	5		x		x	x		
Change in land-usage and	4	4	4	4	5		x		x	x	x	x
Energy security (21)	4	5	4	5	5			x	x	x	x	x
Energy sovereignty (22)	1	1	1	1	5				x			
Community acceptance (23)	3	4	3	4	5		x		x			
Race (24)	5	3	5	3	5				x			
Gender (25)	5	3	5	3	5				x			
Income group (26)	4	3	4	3	5				x			
REFIT (27)	2	4	2	4	1		x	x	x	x	x	x
CDM/CER (28)	4	2	4	5	1		x	x	x	x	x	x
Other (29)					1							
Total	5.1875	4.59125	4.9375	5.34875								

Fig.5.10: The Technical Process and Product Requirement vs. Sustainability Criteria Matrix

The integration of the matrices with the rapid assessment and communication tool known a STBS results in the figure 5.11 below.

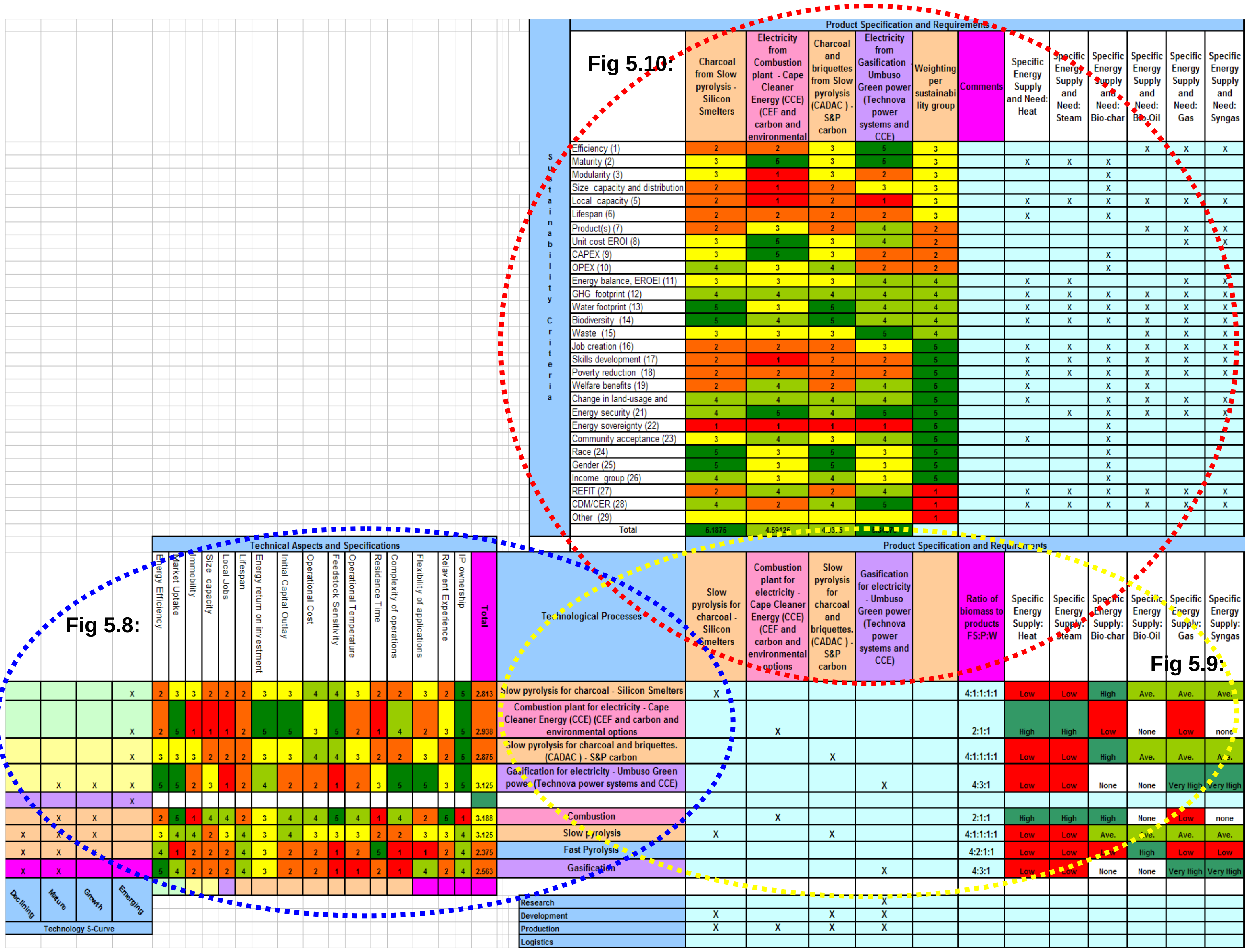

Fig.5.11: The Complete Sustainable Technology Balance Sheet indicating Technical and Sustainability performance through ranking. The positions of the different preceding evaluation matrices are shown by the dashed circles.

Note:

The colour coded ranking system indicates desirable sustainability characteristics through a numeric and colour scale with a high sustainability indicated by a comparison ranking of 5 within a green block and a low sustainability indicated by a comparison ranking of 1 within a red block and all subsequent comparison ranks including 4, 3 and 2 indicated by coloured blocks of light green, yellow and orange respectively.

The addition of an X will indicate some form of association between the two indicated factors and provides linkages between matrices.

6. Conclusions and recommendations

Recommendations by stakeholders and experts were diverse, including simple suggestions on framework structure to improve legibility and complex discussions surrounding the communication of STBS factors, driving forces, and underlying logic of the framework. Most suggestions were taken under advisement during the initial development stages and all avenues discussed and the framework amended accordingly.

The mini-workshop with DWAF could be seen as the first acid test within a formal policy environment while retaining the industrial focus of the EOI for the PPPs.

The outcomes included:

- A clear consensus surrounding objectives. That is to say that the original objectives had been either fully or partially addressed, depending on the parameters of importance levied on each objective. It was also indicated that the action points was adequate in fulfilling the objectives required but room for further development remained within each of the objectives thus allowing for further action points to be initiated to improve the framework further.
- Unambiguous understanding of the conceptual framework and underlying logic even if the process would still require a facilitation aspect in order to retain integrity.
- A clear buy-in of all the assessment factors in general was communicated and special attention was given to the Sustainability Criteria factor, the formulation of which was deemed to be of critical importance.
- The effectiveness at which the data surrounding the factors where communicated was commended especially the awareness of the Technical Specification factors.
- The strategic intent and direction was intrinsically communicated by the framework.
- The concern surrounding the trade-off between the rapid assessment and the rigour of the assessment was highlighted and it was concluded that the rigour was dependant on the quality of the data used and rate at which the assessment was required. Both factors can be adjusted within the STBS tool to meet the stakeholder requirements.

Thus, the framework itself provides an accurate communication tool aimed at non-technical stakeholders and political decision-makers at various stages in the project life cycle. It provides them with a simple-to-understand strategic direction, a better understanding of the complex system under review using the implementation process insights, which systems thinking provide. This ensures a much improved stakeholder buy-in as well as general “trust brokering”. The framework acts as a high-level cognitive decision tool making use of stakeholders’ priorities, and together with the implementation process it is designed to compliment and integrate with other tools such as the MCDA and LCA, from which it draws heavily and where the STBS act as a precursor.

The STBS also utilises information generated by other preceding stakeholder engagement tools, thus acting as a truly integrative tool creating a link between other tools and methodologies, which is invaluable to both stakeholders and practitioners alike.
Expert opinions have been positive in regards to the STBS addressing sustainability, its rapid flexibility and its ease of communication.

As a way forward, the STBS needs further refinement and active development by further case study analysis from the IAP and RETs projects. The case study requirement is based on specifically utilising the STBS from an early project stage and providing focus for the STBS as the main strategic assessment tool. This would, however, be done in relation to and in close conjunction with other integrative tools developed so as to add value to the STBS and other tools utilised.

The need for open dialog among experts, academics and practitioners within the field of TA will remain a constant focus and requirement for further development and will be actively sought. The transfer of the sustainable TA concept is of great importance so that it may lead to a variety of constructive and enlightened conversation surrounding the further implementation within relevant sectors. It is also only though the proposition of theories and the expressions of opinions that the stimulation of controversial conversations can occur and ultimately lead to shifts within a paradigm.
Thus a better general awareness of issues surrounding TA is of great importance.

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Appendices

Appendix A.1: Sustainability Criteria for the Lucingweni Case Study:

The Millennium Development Goals:

The MDG is also made use of within the governing bodies of South Africa to assist in the alignment of policies to the needs of the people, thus it is critical to acknowledge these methodologies within our framework so as to ensure that the frameworks' outcomes remain relevant to the aims and goals of those who provide the institutional environment while efficiently contributing to sustainability of systems which improve our general existence and better peoples lives.

Within the case study use was made of a Millennium Development Goal Model for South Africa (SA) to describe the relationship between the social, economic, and energy systems, i.e., the primary objective of the SA Development Goals is to halve wide scale poverty (Brent and Rogers, 2009). The means of alleviating the poverty identified was by increasing per capita income of large numbers of impoverished people by way of increasing productivity of the work force (Brent and Rogers, 2009). This is achieved by increasing skills and life expectancy of the productive part of the population.

The considerations given to the MDG are summarised in Table A.1 which indicate the criteria and indicators that have been deemed appropriate for this case study by stakeholders. The description and prioritisation of these indicators are provided in Table A.1 and Table A.2.

. In this case comparisons of the sustainability criteria and indicators are made between the criteria and the perceived performance of the product in meeting needs and are divided into two time frames:

- Design,
- Outcome.

Table A.1: The Millennium Development Goals:

Millennium Development Goals and the South African national indicator set in use	Indicator			
	Type[a]	Value	Date of data	Target for 2015
Goal 1: Eradicate extreme poverty and hunger				
1. Proportion of population below $1 (PPP) per day	S	11.30%	2000	5.70%
3. Share of poorest quintile in national consumption	S	3.10%	2000	No target
4. Prevalence of underweight children under five years of age	S	11.10%	1999	5.60%
Goal 2: Achieve universal primary education				
6. Net enrolment ratio in primary education	R	96%	1999	100%
7. Proportion of pupils starting grade 1 who reach grade 5	R	84%	2001	No target
8. Literacy rate of 15-24 year olds	S	98%	2004	100%
Goal 3: Promote gender equality and empower women				
9. Ratios of girls to boys in primary, secondary and tertiary education	R	100%	2001	100%
10. Ratio of literate women to men, 15-24 years old	S	100%	2001	100%
11. Share of women in wage employment in the non-agricultural sector	P	43%	2001	100%
12. Proportion of seats held by women in national parliament	R	33%	2004	50%
Goal 4: Reduce child mortality				
13. Under-five mortality rate per 1000 live births	P	60	2002	20
14. Infant mortality rate per 1000 live births	P	44	2002	15
15. Proportion of 1 year-old children immunised against measles	R	78	2003	90
Goal 5: Improve maternal health				
16. Maternal mortality ratio per 100 000 live births	P	124	2002	38
17. Proportion of births attended by skilled health personnel	R	84%	1998	90%
Goal 6: Combat HIV/AIDS, malaria and other diseases				
18. HIV prevalence among pregnant women aged 15-24 years	P	20%	2004	Stop growth
19. Condom use rate of the contraceptive prevalence rate	R	28%	2002	No target
21. Prevalence and death rates associated with malaria per 1000 deaths	P	1.8	2002	No target
22. Proportion of population in malaria-risk areas using effective malaria prevention and treatment measures	R			No target
23. Prevalence and death rates associated with tuberculosis	P	132	2002	No target
24. Proportion of tuberculosis cases detected and cured under directly observed treatment short courses DOTS	R	68%	2002	85%
Goal 7: Ensure environmental sustainability				
25. Proportion of land area covered by forest	P	11%	1995	No target
26. Ratio of area protected to maintain biological diversity to surface area	R			No target
27. Energy use (kg oil equivalent) per $1 GDP (PPP)	P	283	2001	No target
28. Carbon dioxide emissions per capita and consumption of ozone-depleting CFCs (ODP tons)	P			No target
29. Proportion of population using solid fuels	R			No target
30. Proportion of population with sustainable access to an improved water source, urban/rural (%)	R	88/64	2004	85/72
31. Proportion of population with access to improved sanitation, urban/rural	R	77/45	2004	74/63
32. Proportion of households with access to secure tenure	R	72	2001	No target
Goal 8: Develop a global partnership for development				
Official development assistance (ODA) indicators 33 to 37 not used	-			No target
National and international market access indicators 38 to 41 not used	-			No target
National and international debt sustainability indicators 42 to 44 not used	-			No target
45. Unemployment rate of young people aged 15-24 years, each sex and total[b]	P	52%	2004	No target
46. Proportion of population with access to affordable essential drugs on a sustainable basis	R			100%
47. Telephone lines and cellular subscribers per 100 population	R	19	2003	No target
48. Personal computers in use per 100 population	R	7	2001	No target
Internet users per 100 population	R	3	2001	No target

This in turn was then used to generate a matrix, which compares performance of the various criteria and provides a rationale for the indicated performance and how it was devised. Table A.2 indicates the matrix of the given comparisons.

Table A.2 Sustainability Performance:

	Sub-system	Priority	Indicator	Designed for change	Outcome from change	Measurable unit	Explanation of measurement	How the success of the project was determined by performance measured with this indicator
1	**Economic indicators**	A	Purchase Power Parity (PPP)	None	?	USD pc per day	International benchmark of ability to meet basic needs with available resources	Increase in wealth through productivity was not planned. There are no data on changes since 2004.
2		A	Gini coefficient	Some	None	% Income lowest quartile	Share of poorest quintile in consumption.	Gini is implicit in the electrification programme, i.e., free electricity will improve equality. But the plan did not include all the households in the village. Technically improved access was planned, but not acceptably to the traditional institutions. Outcome is no electricity. **Project outcome fails on this indicator**
3		A	Health	Some	None	10 years of adult working life	WB model health of adults for productivity; 0.4% productivity per 10 years life expectancy	Expected to improve safety of drinking water by borehole pumping and filtration. The clinic is outside the service area and has its own PV system. The villagers already had cholera free water from rain, and therefore did not need electricity for health. There was not enough power for the houses and the borehole.
4		B	Education	Some	Some	Years education working adults	WB model education of adults for productivity: 0.5% productivity per year at school	Although schools have their own PV system, additional study time would have been achieved through lighting at night.
5		C	Access to basic services	Yes	None	No units	Basic services are required for productivity	Cell phones operate already. Transport is not affected. Clean borehole water was intended, but not achieved.
6		B	Positive return on energy investments	Yes	?	(Net output energy/net input energy) %	Energy output of system > factor of energy cost of inputs; to ensure viable energy supplies	PV plates and wind turbines have demonstrated pay back times. Batteries and energy conversion technologies pay back times not available during the project.
7		D	Affordability of energy	None	Too expensive	% of income/ disposable resources	Energy cost for users is affordable	Not designed in the institutional framework. R 8/kW hr is 26 times more expensive than ESKOM subsidized power and the capital investment for the responsible institution is 8 times more expensive than for ESKOM. R8 /kW-hr may be affordable to the residents for lighting but this was not planned for. **Project fails on economics technology and institutional design on this indicator.**
8	**Legal/ Institutional**	A	Allocation & control of resources	None	None	Contracts/ agreements	Contracts/agreements between parties with service providers and users are	1. The municipality has not budgeted this energy within the "indigent grant" policy, i.e., 2. A service provider has not been contracted

	Sub-system	Priority	Indicator	Designed for change	Outcome from change	Measurable unit	Explanation of measurement	How the success of the project was determined by performance measured with this indicator
							carried out within acceptable legal /institutional frameworks.	3. The roles of the Traditional Leadership, the municipalities, and the national responsible support departments' officials have not been defined as required by the Acts. 4. There are disagreements on costs and technical requirements indicating poor contracting between all institutions and commercial parties 5. There is no "owner" for the energy system 6. It was not planned to serve all the households in the village. 7. More houses were connected by the residents than the system could supply. **Project institutional design fails on this indicator**
9		B	Legal protection for controls	None	None	Contracts and working services	Legal protection to controls for resources: This is via contracts between the suppliers and the users	Consumers take more than their quota of electricity and are not disconnected or punished. The residents want electricity but have no service agreements that can be enforced. No working service is the result.
10		C	Access to credit	None	None	Loans	Access to credit is required to enable economic activity	No change planned, or occurring.
11		C	Post Kyoto CO_2 eq. targets	Some	None	Tonnes CO_2 eq.	Land use and fossil fuel release measured by global warming gases.	An intention to reduce CO2 emissions by PV and wind as an alternative to ESKOM fossil power for basic services is indicated, but not planned in the documents available to the project. i.e. 1. No provision of energy to replace biomass for cooking or heating. 2. No plan to stop forest wood fuel burning. 3. Preventing carbon release associated with soil degradation is not planned; forest is destroyed for vegetable gardens.
12		D	Access to basic resources	Yes	3 months intermittent access for a 20 year project	National standards for basic needs: 20 kW hr pm or R55 pm for electricity	Access to basic resources is government policy for affordable access to all households by 2014	30 kW-hr was planned and met the institutional standard for a household. But at R 240 per month per household was too expensive for the institutions. Therefore the project would fail both economically and institutionally.
13	**Ecology**	A	Biological community diversity	None	?	Acceptable trend	Resilience of ecosystem is indicated by diversity of indicator populations	Not planned for. Observed loss of forest in the village area is expected to result in lower diversity. .
14		B	Soil type maintenanc e (fertility)	None	?	Acceptable trend	Resilience of ecosystem is indicated by trends in soil fertility	Not planned for. Unused grasslands and fresh cutting of forest for new vegetable gardens indicates reduced fertility and loss of resilience. Data on the outcome of project failure on loss of fertility is not available.
15		A	Availability of energy	Either errors in	System unstable	% of basic need for energy met	Energy conversion technology with availability of wind/sun	According to draft final project design, there is not enough wind and sun at the site to make the wind and sun conversion technology

	Sub-system	Priority	Indicator	Designed for change	Outcome from change	Measurable unit	Explanation of measurement	How the success of the project was determined by performance measured with this indicator
			resource	determining availability of wind and sun or incorrect design			should meet basic needs.	economically viable, i.e., a 50 to 200% excess peak capacity is required for this turbine PV and domestic supply. **Technology design fails on this indicator. Can larger vanes be used on the turbine?**
16	**Sociology**	A	Jobs (ability to get food)	None	None	Hours of saleable-production/work	Best indicator of ability to self support for basic needs	Not designed for. It appears that most residents are already fed, housed, educated, cared for, and clothed with the current income i.e., basic needs are met already. This contrasts with the StatsSA poverty rating of 83%. There is no direct or indirect benefit from the project.
17		B	Nutrition	None	?	Stunting of children	Best indicator of nutrition and that affects productivity and ability to learn	Not observation competency within this project.
18		B	Life expectancy	None	?	Years	Best overall measure of resilience of social systems	Not measurable in these time scales
19		C	Literacy	Yes	3 months intermittent access for a 20 year project	Standard literacy test	Best overall indicator of ability to improve productivity	Although not stated overtly in the project plan, the design for provision of domestic electrical lighting encompasses improved capability for night time studies to support learning for literacy.
20	**Technology**	E	Increased productivity	None	None	% Increase in production	Production increases income	No change designed for the project or possible due to failure of the mini-grid.

Appendix B.1: Sustainability criteria: Working for Energy

To enhance the implementation process for this specific case study it was necessary to investigate the understanding of the various sustainability concepts within this specific sector. A literature search provided insights into the following methodologies and definitions.
Sustainability criteria are a set of definitions of the different factors or aspects that should be considered in the evaluation of technological processes. These are to be understood in a complementary and interdependent manner and linked to goals and principles related to the sustainable development of the country. These effects on socio-environmental aspects of the various populations are also to be assessed (FBOMS, 2006).

Sustainability indicators are the parameters that can be used as a measure of compliance with these criteria and are given specific units so as to standardise the evaluation (FBOMS, 2006).

The Sustainability criteria highlighted from the various DWAF documents include the following:

Ecological:

- Decrease water usages and increase available water - To enhance water security through regaining control over Invader plants in South Africa and to promote the quest for equity, efficiency and sustainability in the supply and use of water.
- Decrease IAPs - To improve the ecological integrity of our natural systems through the removal of Invader plants,
- Decrease abnormal fires by removing excessive and dense abnormal invader biomass
- Increase natural vegetation and ecological systems – thus decreasing soil erosion, flooding, scouring of rivers, siltation of rivers, dams and estuaries, and
- Increase natural vegetation and ecological systems - to protect and restore biological diversity.
- Increase agricultural viable land - To restore the productive potential of land, in partnership with the *Land Care* and *Combating of Desertification* initiatives,
- Decrease the use of unsustainable natural resources - to promote the sustainable use of natural resources.

Social:

- Enhancing their quality of life:
    - Access to resources:
    - Water
    - Energy
    - Housing
    - Education
    - Health Care

  - Entrepreneurship
  - Improved Nutrition

- Focus on local communities - benefits community-based, Localised Benefits:
  - Job creation
  - Skill development
  - Increase Disposable Income
  - Improvement of resources accessibility

- Focus on the poor - public-works programme by investing in the most marginalized sectors in South African society.
  - Unskilled labour
  - Equal opportunities for females

Economic:

- To develop the economic benefits derived from clearing these plants (i.e. from land, water, wood and trained people),
  - Cheap energy resources
  - Skill transfer
  - New arable land
  - More water

- by facilitating economic empowerment
  - more freedom
  - more choice
  - greater self reliance

- the development of value added-industries,
  - Entrepreneurship
  - Formal and informal economic growth
  - Access to services

- to help to protect the economic integrity of the productive potential of the country.

The Energy Working Group (GTE) of the Brazilian Forum of NGOs and Social Movements (FBOMS, 2006), with the experience of its members in dealing with populations affected by energy projects, created specific sustainability criteria with the hope to contribute to ensuring that the expansion of energy supply from biomass – whether through liquid bio-fuels, electricity generation from plant residues and other biomass sources – planned for the coming years, occurs in a manner that respects traditional cultures and ways of life, promotes social inclusion and local sustainable development, while at the same time contributes to replacing fossil fuel use and reducing associated problems of pollution and global warming (FBOMS, 2006).

In the same way in which concept generation must take place among the stakeholders within the implementation process, so to the generated set of sustainability criteria and indicators for the generation of renewable energy from biomass were discussed within the Energy Working Group of FBOMS (2006), in an attempt to contextualise and deepen the national and international debate about future initiatives, in a participatory and engaged manner.

It was believed that the amalgamation of these suggestions could make a tool for organisations to influence national and international policies being developed or implemented in this area, as is the case of, the Clean Development Mechanism (CDM) and the international trade negotiations involving bio-energy (FBOMS, 2006).

The table below illustrates both the general criteria – basic criteria applicable to any type of project - and specific criteria - for projects that involve the use of bio-energy.
It also presents, for each criteria considered, the ideal situation and recommendations for full compliance, as well as factors involved in achieving this Undesirable refer to situations that cannot be considered to be in accordance with the proposed sustainability criteria (FBOMS, 2006).

Table B.3: General criteria – basic criteria applicable to any type of project - and specific criteria - for projects that involve the use of bio-energy. (FBOMS, 2006)

Criteria	Desirable	Prerequisites	Undesirable	Indicators
Social accountability	local acceptance of who and what the energy is for; electrical generation for isolated communities	information and capacity-building	energy for internal use by energy-intensive industries	participation of local population and national socio-environmental organizations in project design
Participation in decision-making	both beneficiaries and affected populations have influence in decision-making	information and training political forums for participation with real influence over decisions	public consultations with no commitment to consider demands and with no influence on decisions	number, sites, nature and types of consultations, form of publicity, access to information, language and accessibility of material used
Type of management	Cooperatives, community associations	training for management of cooperatives, financing (PRONAF / BNDES)	traditional agribusiness, contracts involving integrated production systems that create unfair working and business conditions	organizational structure and forms of decision-making, number of participants/decision-makers, involvement of organizations representing local workers, participation of women
Job creation and income generation	family agriculture; jobs for local population, creation of conditions for youth employment	training for creation of cooperatives, awareness and training of families with technical and political information	capital intensive agribusiness, concentration of income and land ownership, local population involved only in low-skilled jobs	number of jobs per unit of energy (production chain, implementation and operation), profit sharing, generation of new local opportunities and sources of income, relation between local jobs before and after the project, indexes of increase in acquisitive power of the local population
Social inclusion	capacity-building and training in technology, involvement of community surrounding the project; social support to the families involved; leads to improved quality of life of women and youth	Sharing of project benefits with local population	absence of community involvement; disruption of traditional patterns of subsistence and culture	number of families previously without access to energy who benefit from the project; measures of quality and compliance with accepted standards of the involuntary resettlements, when necessary and accepted; impact on the quality of life of the communities; social programs, especially for health and education; epidemiological assessment and monitoring; contribution to access to services and infra-structure on the part of local populations to education, energy, garbage and sewage services, etc.; contribution to adult literacy and environmental education; reduction of violence and vulnerability of women and youth

Criteria	Desirable	Prerequisites	Undesirable	Indicators
Social accountability	local acceptance of who and what the energy is for; electrical generation for isolated communities	information and capacity-building	energy for internal use by energy-intensive industries	participation of local population and national socio-environmental organizations in project design
Participation in decision-making	both beneficiaries and affected populations have influence in decision-making	information and training political forums for participation with real influence over decisions	public consultations with no commitment to consider demands and with no influence on decisions	number, sites, nature and types of consultations, form of publicity, access to information, language and accessibility of material used
Type of management	Cooperatives, community associations	training for management of cooperatives, financing (PRONAF / BNDES)	traditional agribusiness, contracts involving integrated production systems that create unfair working and business conditions	organizational structure and forms of decision-making, number of participants/decision-makers, involvement of organizations representing local workers, participation of women
Job creation and income generation	family agriculture; jobs for local population, creation of conditions for youth employment	training for creation of cooperatives, awareness and training of families with technical and political information	capital intensive agribusiness, concentration of income and land ownership, local population involved only in low-skilled jobs	number of jobs per unit of energy (production chain, implementation and operation), profit sharing, generation of new local opportunities and sources of income, relation between local jobs before and after the project, indexes of increase in acquisitive power of the local population
Social inclusion	capacity-building and training in technology, involvement of community surrounding the project; social support to the families involved; leads to improved quality of life of women and youth	Sharing of project benefits with local population	absence of community involvement; disruption of traditional patterns of subsistence and culture	number of families previously without access to energy who benefit from the project; measures of quality and compliance with accepted standards of the involuntary resettlements, when necessary and accepted; impact on the quality of life of the communities; social programs, especially for health and education; epidemiological assessment and monitoring; contribution to access to services and infra-structure on the part of local populations to education, energy, garbage and sewage services, etc.; contribution to adult literacy and environmental education; reduction of violence and vulnerability of women and youth

The core list of standards introduced in the Sustainability standards for bio-energy document can be broadly categorized in a governance system in terms of scope, the need for regional adjustment, and the time horizon for implementation (Oko-Institut).

As a summary of standards recommended by the WWF is provided below:

Table B.4: Sustainability standards recommended by the WWF

Standard	Scope	Regional Adjustment	Time Horizon
Clarification of land ownership	regional/local	no	short-to-medium term
Avoiding negative impacts from bioenergy-driven changes in land use	global	no	short term
Priority for food supply and food security	regional/local	yes	medium-to-long term
No additional negative biodiversity impacts	regional/local	yes	medium-to-long term
Minimization of greenhouse gas emissions	global	no	short term
Minimization of soil erosion and degradation	regional/local	yes	short-to-medium term
Minimization of water use and avoidance of water contamination	regional/local	yes	short-to-medium term
Improvement of labor conditions and worker rights	regional/local	no	short term
Ensuring a share of proceeds	regional/local	no	short term
Avoiding human health impacts	regional/local	no	medium-to-long term

Source: Compiled by Öko-Institut

Appendix B.2: The proposed sustainability criteria for the STBS:

After taking all of the various literature sources into account, a number of informal workshops were held to generate an expert opinion and to test the general consensus among sustainability practitioners. Once this consensus was roughly established the following sustainability criteria was further discussed and generally accepted by all stakeholders including DWAF. DWAF's only interceding comment was that these were not to be viewed as the complete set of criteria but as a baseline to which can be added as the situation dictates.

ECONOMIC

1. Unit cost (R/kW electricity and/or heat)
1.1 CAPEX
1.2 OPEX (maintenance, feedstock cost, transport cost)

ENVIRONMENTAL

1. Carbon Balance
2. Water balance
3. Waste production
3.1 solids
3.2 liquid
3.3 gases

SOCIAL

1. Job creation
2. Skills development
3. Poverty reduction and welfare benefits
4. Change in land use and practices
5. Local beneficiation
5.1 energy security and
5.2 energy sovereignty) and
5.3 community acceptance
6. Equity
6.1 race, gender and
6.2 distribution of benefits to different communities (rural, urban, peri-urban)

TECHNOLOGY

1. Efficiency (coefficient of performance)
2. Maturity of technology
3. Modularity
4. Size and distribution
5. Local technology capacity
6. Lifespan of technology

7. Technology maturity
8. Products (fuel and/or electricity and secondary products)

POLICY and GOVERNANACE

1. REFIT
2. CER and CDM opportunities
3. DWAF subsidy
4. Other subsidies
5. Other incentives

These criteria, generated from the WfE project documents, were then taken and suitably expanded and formalised to be used for the evaluation of tenders and projects, which will occur at a later stage. This gave rise to Table B.5.

Appendix B.3: IAP Sustainability criteria (*Stafford,* 2009.)

Table B.5. Criteria expanded and formalised to be used for tenders and projects.

Company/Companies involved	**Sustainability Criteria**							
	Technology	**Economic**	**Environment**		**Social**			**Governance**
	Efficiency (1) Maturity (2) Modularity (3) Size capacity and distribution (4) Local capacity (5) Lifespan (6)	Product(s) (7) Unit cost EROI (8) CAPEX (9) OPEX (10)	Energy balance, EROEI (11) GHG footprint (12) Water footprint (13) Biodiversity (14)	Waste (15)	Job creation (16) Skills development (17) Poverty reduction (18) Welfare benefits (19) Change in land-usage and practices (20)	Local benefits	Equity	REFIT (27) CDM/CER (28) Other (29)
				solids liquids gases		Energy security (21) Energy sovereignty (22) Community acceptance (23)	Race (24) Gender (25) Income group (26)	
Silicon Smelters	**Slow pyrolysis for charcoal** 7000t charcoal per month from 52000t/month timber. Use >30mm trees and dry for 3-6 months							

Cape Cleaner Energy (CCE) (CEF and carbon and environmental options Partner with Sikicon Smelter to use IAPs that are not utilised by Silicon Smelters	**Combustion plant for electricity** 1MWe= 15000t IAP (@52% moisture). Electricity for George municipality: 30MW Eden plant Project life 25 years							
S&P carbon	**Slow pyrolysis for charcoal and briquettes.** CADAC 50km2 area. 6000t/month. Bredasdorp/ Augulhas. Plans to develop in further areas							
Umbuso Green power (Technova power systems and CCE)	**Gasification for electricity** Modular 5MW plants. Estimated 25MW using 60 000t/year for each 5MW plant							

1. Efficiency of the technology process (es), in terms of energy, produced from the energy source. Depending on the technology, the generated useful energy product(s) may be electricity or fuels (that can be used to produce heat or electricity) and should be stated as Eff(h) and Eff(e) to refer to the efficiency to produce heat and electricity. Where the desired product is electricity, the approach can be standardised so that technologies are compared using Eff(e) by considering that the conversion of a fuel to electricity with a standardised efficiency (i.e. large coal-fuelled electrical generating plant at 46%). Expressed as a fraction Efficiency = Q(out)/Q(in)
2. Maturity. A technology is deemed proven if it has a track record of 8,000 to 16,000 operating hours. The maturity index on reliability index (MIR) defines 5 levels.

(0) The manufacturer has no relevant quantitative evidence of the process output (e.g. field behaviour) of the products. Consequently, there are no control loops from service back to production and development.
(1) The manufacturer has quantitative evidence of the process output of the products and the information is fed back into the process, but the origin of the problems/deviations is unknown.
(2) The manufacturer has quantitative evidence of the process output, knows the origin of the problems (such as design, production, material or customer use), has the corresponding control loops, but does not know what actually causes the problems.
(3) The manufacturer has quantitative evidence of the field behaviour, knows the origin of the problems and knows what actually causes them, and has the corresponding control loops and is able to solve problems. The manufacturer is, however, not able to prevent similar events from happening in the future again.
(4) The manufacturer has quantitative evidence of the field behaviour, knows the origin of the problems, and knows what actually causes them and what to do about it. The level of knowledge is such that the manufacturer not only knows root causes of problems (technical and organizational) but is also able to anticipate and prevent similar problems in the future.

http://www3.interscience.wiley.com/cgi-bin/fulltext/69500177/PDFSTART

3. Modularity and immovability. These are important aspects to consider when the energy source is not renewable and/or decentralised options are being considered. The modularity can be defined as: plant size/subunits constituting the energy plant. If the energy plant has no modularity then Modularity=1, while plants that are modular will have values >1. Immovability refers to the ease at which the energy plant can be relocated (deconstructed and reconstructed, ignoring the transport cost to the new location). This can be expressed as a cost: Immovability= Time period after which relocation is required/Cost of relocation. To avoid complicated projections, the cost is assessed at present day value. Large values for immovability are desirable since they express energy plants that can easily be moved. Immovability= (Cost of proposed plant at defined location)/(Cost of relocation). Therefore, if the relocation involves considerable work in deconstruction and reconstruction then the immovability will be <1. Ideally movable energy plants will have immovability=1.
4. Size capacity. The capacity of the energy plant and can be defined by: Size capacity= (the peak power production of the energy plant/land area occupied by the energy plant). This reflects the power production capacity as a function of land usage. Distribution refers to how centralised the energy plant is at a local level and can be expressed as: Distribution=(peak power production of the energy plant) x (number of power plant sub-units). Note that sub-units can only be considered if the generate a common market product in the energy supply chain.

5. Local capacity. The level of local human capacity to produce and install the power plant. It can be defined as: Local capacity=(total local human capacity cost for the construction and operation and servicing of the energy plant/total imported human capacity cost for the construction, operation and servicing of the energy plant). The boundaries of what is local need to be defined. A standard would be to consider local within South Africa, but if more localised human capacity development is required it can be defined as human capacity available within a certain radius (i.e. $50km^2$) of the energy plant.
6. Lifespan. The predicted lifespan (time) of the energy before the plant is needs to be de-commissioned (energy resource diminished or technical failure due to wear and tear).
7. Products. Products from the energy plant that are destined for a defined market. These may be fuels (gas, solid or liquid), heat or electricity and should be given a present day value in ZAR (R/W, R/kg, R/m^3).
8. The unit cost uses the Energy return on investment, EROI. This is different from EROEI (11). EROI= (generated energy)/(total cost of the energy plant). This is calculated over the plants lifetime or lifespan (see point 6).
9. CAPEX. Capital expenditures (CAPEX or capex) are expenditures creating future benefits. A capital expenditure is incurred when a business spends money either to buy fixed assets or to add to the value of an existing fixed asset with a useful life that extends beyond the taxable year.
   http://www.investopedia.com/terms/c/capitalexpenditure.asp
10. OPEX. Operational expenditure or OPEX is an on-going cost for running a product, business, or system.
    http://en.wikipedia.org/wiki/Operating_expense
11. Energy return on energy invested, EROEI. EROEI = (Usable energy produced)/(Energy expended). It gives a measure of how easily exploitable an energy source is and the performance of the project since it is the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource. The EROEI therefore reflects the balance of energy of the system and assesses the efficiency of the project in terms of the total energy expended in acquiring an energy product.
    http://en.wikipedia.org/wiki/EROEI
12. Greenhouses gas (GHG) footprint (m3/W) is the GHG potential per unit power generated. The total GHG potential is determined using a weighted system that takes in to account the global warming potential of different gases. The GHG footprint = (Volume of GHG produced x GWP)/(net unit power produced by the energy plant).
    The Global warming potential (GWP) values and lifetimes from 2007 IPCC AR4 (http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf). They time period can be considered long-term (100 years) or short term

(20 years) and should be defined in the tender. Carbon dioxide has a GWP of exactly 1 (since it is the baseline unit to which all other greenhouse gases are compared).

GWP	**20 years**	**100 years**
Methane	72	25
Nitrous oxide	289	298
HFC-23 (hydrofluorocarbon)	270	12,000
HFC-134a (hydrofluorocarbon)	14	3830
Sulphur hexafluoride	3200	16,300

13. Water footprint (L/W) = the amount of water used in the energy/unit power produced. Account for water quality factors. Drinking-quality water is more of a valuable resource than water of non-drinking quality, a water quality factor can be devised (0-1.0), where 0 indicates water that is heavily polluted and considered unusable, and 1 is quality potable water. This quality factor can be based on defined water quality parameters.
14. Biodiversity footprint is the effect of the energy plant on the biodiversity. The biodiversity can be quantified as species/unit area and given an economic value? Changes in biodiversity will be predictive and require baseline data. Gini coefficient has been used as a measure of biodiversity, where the cumulative proportion of species is plotted against cumulative proportion of individuals (Wittebolle, Lieven; *et al* (2009). "Initial community evenness favours functionality under selective stress", Nature 458: pp. 623-626).
15. Waste footprint = the solid, liquid and gas wastes produced by the energy-plant/unit power produced.
16. Job creation. The amount of jobs created (people newly employed) as a result of the energy plant.
17. Skills development. The amount of skilled jobs created as a function of the total jobs created. Skills development= (number of people-hours spent in training)/(number of people hours spent during construction and operation of the energy-plant).
18. Poverty reduction. The change in income per capita as a result of the energy plant. Poverty reduction = Human Poverty Index after energy plant/ Human Poverty Index before energy plant. Values >1 indicate a reduction in poverty. The Human Poverty Index is an indication of the standard of living in a country, "A composite index measuring deprivations in the three basic dimensions captured in the human development index — a long and healthy life, knowledge and a decent standard of living.

http://en.wikipedia.org/wiki/Han_Poverty_Index

19. Welfare benefits. Other welfare benefits such as improved access to transport, electricity/ fuels, social structure as a result of the energy plant. Needs to be assessed by engagement with interested and affected parties and scored using a questionnaire.
20. Change in land use and practices. Needs to be assessed by engagement with interested and affected parties and scored using a questionnaire.
21. Energy security. Confidence in the security of energy supply. Needs to be assessed by engagement with interested and affected parties and scored using a questionnaire.
22. Energy sovereignty. Degree of ownership and control of the energy plant. Needs to be assessed by engagement with interested and affected parties and scored using a questionnaire.
23. Community acceptance. Needs to be assessed by engagement with interested and affected parties and scored using a questionnaire.

24-26. Equity (the spread of benefits) assessed before and after the energy plant. The changes in equity need to be assessed with the defined groups (race, sex, income group) and expressed as % change. The income groups are those defined by the Department of Inland Revenue (ref). The equity is measured by a Gini coefficient using gross income per capita as the parameter.

27. CDM/CER. South Africa has ratified the Kyoto Protocol[1], which this allows for Clean Development Mechanism (CDM) projects to be initiated within developing countries. If the development involves renewable energy and energy efficiency that achieves emission reductions then globally tradable credits, Carbon Offset Credits, can be generated. There are also the Carbon Reduction Credits generated by the collection and storage of carbon-dioxide through carbon capture and sequestration (bio-sequestration by biomass and storage beneath the land or sea, see Carbon storage atlas).

28. The Renewable Feed-in Tariffs (REFIT) guarantees prices for renewable energy supply. The REFIT for several renewable energies has recently been established. REFIT (R/kWh):- Wind 1.25, Concentrated solar 2.10, Hydro 0.94, Landfill gas 0.90. http://www.nersa.org.za/UploadedFiles/ElectricityDocuments/REFIT%20Guidelines.pdf

1. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions.

29. Other policies, subsidies, incentives that are drivers for the energy-plant. The government set the renewable energy targets at 5% of the total energy mix (10 000GWh) by 2013 (Renewable Energy White paper 2003). The DME has also established a Renewable Energy Finance and Subsidy Office (REFSO) which manages the provision of a once-off capital grant to projects employing proven renewable energy technologies with a maximum capital cost of less than R100 million. http://www.dme.gov.za/energy/renew_finnace.stm and http://www.thedti.gov.za/tradeinvestmentconference/speaker/RenewableEnergy.pdf

Other notes:

The Gini coefficient's main advantage is that it is a measure of inequality by means of a ratio analysis, rather than a variable unrepresentative of most of the population, such as per capita income or gross domestic product.

The Gini coefficient demonstrates how income has changed for poor and rich. If the Gini coefficient and GDP is, poverty may not be improving for the majority of the population.

Economic inequality predicts biodiversity loss (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1864998/).

Appendix C.1: Renewable energy technologies of the thermal processing of biomass and super structure generation

The following are extracts from Ayoub *et al*. (2007 and 2009) and further explained and elaborated on; Traditionally, biomass has been used for centuries to provide heat and light essential for cooking and keeping warm (Fanchi, 2004).

The current technologies used in processing biomass resources are very different from those previously available and range from fundamental processes, such as burning wood fuels for cooking and charcoal production to complicated thermo-chemical conversion of biomass to gas and power.

There are a large variety of research work on this subject and range from biomass potential estimation to technology research and development (Albertazzi *et al*., 2005; Kim & Dale, 2004; Parikka, 2004;).

The utilisation of biomass for bio-fuels is facing many environmental, economical, and social challenges along their diverse production life cycle.
It has been concluded from reviewing the literature related to the biomass utilisation and specifically work is carried out for the analysis of individual biomass utilisation technologies as well as biomass supply chains for both single and integrated systems of biomass resources (Ayoub *et al*. 2007 and 2009, Albertazzi *et al*., 2005)
There is at present a lack of information in the literatures on the study of complete design methodologies for planning and evaluating biomass systems of multi-resources and multi-products like B-NETs.

During the investigation for the case study we also considered Dornburg's (Dornburg, 2006a; Dornburg *et al*., 2006b) proposed optimisation model that identifies the optimal strategies for biomass and waste treatment systems in terms of primary energy savings and their economical performance and energy saving, however it disregards the impact of environmental factors.
Other shortcomings of their model is that it ignores the affect of different technologies on the reduction or increasing impacts along the individual biomass resources supply chains or life cycles, i.e., Logistics, Mechanised technologies, Auto motor, etc.
The STBS intends to directly address these oversights by addressing the value chain first and foremost so as to generate system thinking and a better awareness of the interactions of the system components.
This thinking provides a backbone to the STBS generation by dictating the components and life cycle stages required to be investigated for a valuable assessment.

Depending on factors, such as biomass resources available, culture, lifestyle, and weather, every local area has its own biomass processing requirements and thus models though which the STBS must be modified to remain successful.

The second step in the STBS is synthesized as macro-level structures, a generic and a specific superstructure of the components within the project value chain/ life cycle. The intent is to provide a holistic view about the available and possible processing network models in workshops and group discussions involving stakeholders and experts.

In the superstructure shown in Fig. C.1, known as the BUSS model (Ayoub, *et al*. 2009) the biomass resources are classified as wet or dry, whereas, the bio-products are categorized into parameters, such as finished products or intermediate products.

the BUSS only communicates the main processing and conversion systems while other processes are represented in a more general way. For example, landfill (permanent disposal), solid waste disposal (solid system), etc., are all modelled in the superstructure as a waste system. The logistics processes are represented by the connectors of main processes.

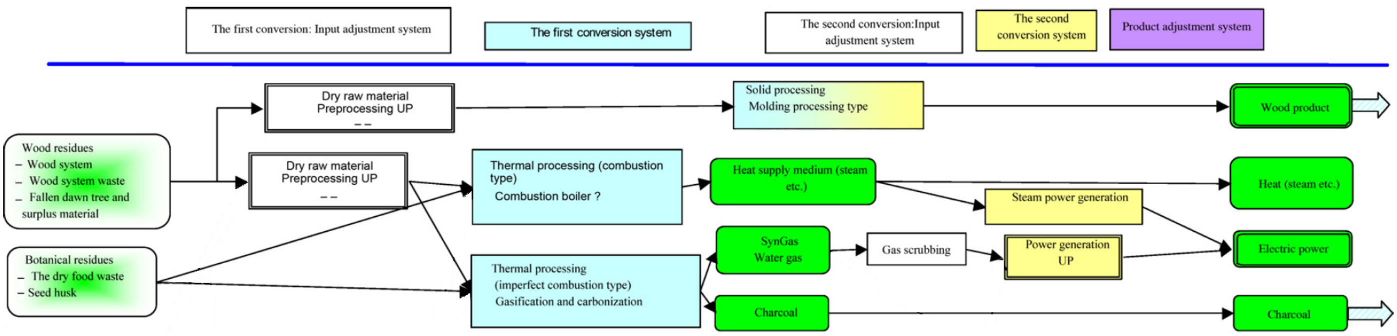

Fig. C.1: The BUSS superstructure is a good tool, which can be used in conjunction to the STBS during the Implementation Process (Ayoub *et al*. 2009).

The BUSS gives a general outline of the available resources and the processes that are available in certain localities and the Network model is a real model that includes the detailed processes and jobs that are applied in the real life situation, i.e. B-NETs.

The BUSS model has generated two types of network models:

1. The reference model and future network model,
2. The reference model communicated current circumstances with its possibilities for improvement. Providing insights with its processes, elemental technologies and based on current regulations.

The future network models either excluding, or partly including, the current utilisation processes and based on new or reformed regulations. The resulted network models can be used as a blueprint for the different scenarios of B-NET that can be evaluated in comparison with the reference scenario. (Ayoub *et al*. 2009).

The B-NETs are classified based on the data of topology, weather, geographical location, and time frame. The renewable institution classes are defined on the basis of renewable resources, and used in allocating the suitable institution for the local area that is understudy.
By analysing the inputs to the local biomass network, such as, available classes of biomass resources, similar classes of local areas, suitable renewable institutions, available processing methods, and future trends, the BUSS is established (Ayoub *et al*. 2009).

Generic renewable energy technologies of the thermal processing of biomass:
Before we look at the specific technologies expressed by the EOI, a general technical overview must be created to aid in the syntheses of technical criteria, which can be used to assess the technologies within the STBS (Bridgwater, 2002).

Combustion:

- Burning in the presence of oxygen (oxidation)
- Most widely used and best established.
- Widely practiced commercially to provide heat and power.
- The technology presents minimum risk to investors.
- The product is heat, which must be used immediately for heat and/or power generation, as storage is not a viable option.
- Overall efficiencies to power are low at typically 15% for small plants up to 30% for larger and newer plants.
- Costs are only currently competitive when wastes are used as feed material such as from pulp and paper, and agriculture.
- Emissions and ash handling remain technical problems.
- The technology viable with, many successful working examples, frequently utilising forestry, agricultural and industrial wastes.
- The energy product used directly as heat or to produce steam to drive a turbine
- Widest range of wood feedstock from small branches to large chunks.
- Thermal efficiencies can be as high as 90% for dry wood, or as low as 30%.
- To generate electricity large amounts of water are required (for the steam)
- **Underfeed stokers:** Fed from underneath, only suitable for small-scale systems
- **Grate stokers:** Most common, well proven and reliable and can tolerate wide variations in fuel quality, biomass is added on one side of the gate and moves under gravity or with mechanical assistance. Combustion occurs in three phases (drying, ignition and combustion of volatile constituents, burning out of the char).
    - fixed grates for small scale combustion systems (typically less than 1 MWth)
    - reciprocating grates for larger scale

- **Fluidised bed combustors:** A bed of inert material (eg. sand particles) suspended by heated air blown in from beneath the bed to combust feedstock
- The biomass fuel.
    - Can be bubbling fluidised bed (BFB)
    - Circulating fluidised bed (CFB)

Gasification:

- Fuel gas produced from biomass by either;
    - partial oxidation to produce a mix of carbon monoxide, carbon dioxide, hydrogen and methane or
    - by steam or pyrolytic gasification as illustrated in Table 1.
- Gasification occurs in a number of sequential steps:
    - drying to evaporate moisture,
    - pyrolysis to give gas, vaporised tars/oils and a solid char residue,
    - gasification or partial oxidation of the solid char, pyrolysis tars and pyrolysis gases.
- Solid fuel is heated to 300–500°C in the absence of an oxidising agent, it pyrolyses to solid char, condensable hydrocarbons or tar, and gases.
- relative yields of gas, liquid and char depend mostly on the rate of heating and the final temperature.
- the rate is the controlling step in gasification, pyrolysis proceeds at a much quicker rate than gasification.
- The gas, liquid and solid products of pyrolysis then react with the oxidising agent—usually air—to give permanent gases of CO, CO_2, H_2, and lesser quantities of hydrocarbon gases.
- Char gasification is the interaction of several gas–solid and gas–gas reactions in which solid carbon is oxidised to form carbon monoxide and carbon dioxide, and hydrogen is generated through the water gas shift reaction.
- The gas–solid reactions of char oxidation are the slowest and limit the overall rate of the gasification process.
- The gas composition is influences factors such as feed composition, water content, reaction temperature, and the extent of oxidation of the pyrolysis products.
- Not all the liquid products from the pyrolysis step are completely converted to gas and these give rise to contaminant tars in the gas. This aspect of tar cracking or removal in gas clean up is one of the most important technical uncertainties in implementation of gasification technologies.
- Products are the CO, H_2 and CH_4 as the main combustible components of the gas.
- This ‘syngas’ can be burnt to generate heat for a boiler or upgraded be used as a fuel for a gas turbine, or a gas engine,
- Common Gasification reactors:
    - Fluidised bed technology, and
    - Moving bed technology

- Products;
    - The fuel gas quality requirements are very high.
    - Tar remains the most significant technical barrier.

- The gas is very costly to store or transport so it has to be used immediately.
- Hot-gas efficiencies for the gasifier (total energy in raw product gas divided by energy in feed) can be as high as 95–97% for close-coupled turbine and boiler applications, and up to 85% for cold gas efficiencies.
- In power generation, using the combined cycle operation, efficiencies of up to 50% for the largest installations have been proposed which reduces to 35% for smaller applications.

Our assessment yields very little information on costs, emissions, efficiencies, turn-down ratios and actual operational experience of the various technologies especially the novel and less commercialised (Bridgwater, 2002).

- **Atmospheric circulating fluidised bed gasifiers**:
  - very reliable with a variety of feed stocks
  - easy to scale up from a few MWth up to 100 MWth.
  - preferred system for large-scale applications
  - high market attractiveness and are technically well proven.

- **Atmospheric bubbling fluidised bed gasifiers:**
  - reliable with a variety of feed stocks at pilot scale
  - small to medium scale up to about 25 MWth.
  - limited in their capacity size range
  - more economic for small to medium range capacities.
  - market attractiveness is relative high as well as their technology strength.

- **Pressurised fluidised bed systems**:
  - limited market attractiveness
  - more complex operation of the installation
  - additional costs related to the construction of pressurised vessels.
  - advantage in integrated combined cycle applications as the fuel gas is compressed ready for use in combustion chamber

- **Atmospheric downdraft gasifiers**:
  - Small-scale applications up to about 1.5 MWth
  - Aimed at developed and developing economies
  - efficient tar removal is still a major problem and
  - a higher level of automation is needed especially for small-scale industrial applications.
  - Improvement of catalytic conversion of tar gives system hope
  - average technical strength.

- **Atmospheric updraft gasifiers:**
  - little market attractiveness for power applications.
  - high tar levels in the fuel gas,
  - recent developments in tar cracking provide hope
  - upper size of a single unit is around 2.5MWe

- larger plant capacities require multiple units.

- **Atmospheric cyclonic gasifiers**:
  - only recently been tested for biomass feed stocks
  - medium market attractiveness due to simplicity, they
  - unproven.

- **Atmospheric entrained bed gasifiers:**
  - very early stage of development
  - require feedstock of a very small particle size,
  - market attractiveness is very low.

No company is known to be developing pressurised systems for downdraft, updraft, cyclonic or entrained bed gasifiers for biomass due to the inherent problems of scale, tar removal and cost.

In conclusion, for large-scale applications the preferred and most reliable system is the circulating fluidised bed gasifier while for the small-scale applications the downdraft gasifiers are the most extensively studied. Bubbling fluidised bed gasifiers can be competitive in medium scale applications. Large-scale fluidised bed systems have become commercial due to the successful co-firing projects while moving bed gasifiers are still trying to achieve this. (Bridgwater, 2002).

Products of Gasification:
Syngas, synthetic petroleum products, heat and electricity

Pyrolysis:

- Thermal degradation of biomass in absence, or partial absence, of air at high temperature (350°C-600°C)
- The Energy products are in three forms:
  - a solid in the form of charcoal,
  - a liquid in the form of oil,
  - a gas.
- The first step in combustion and gasification processes where it is followed by total or partial oxidation of the primary products.
- Lower process temperature and longer vapour residence times favour the production of charcoal.
- High temperature and longer residence time increase the biomass conversion to gas and
- Moderate temperature and short vapour residence time are optimum for producing liquids.
- The ratios of the three products related to the operating process are shown in Table C.6. (Bridgwater, 2002).

Table C.6: Product ratios for fast and slow pyrolysis

Products	Slow Pyrolysis	Fast (flash) Pyrolysis
Liquid (bio-oil)	30% – 35%	60% – 80%
Gas	25% – 30%	12% – 20%
Solid (charcoal)	20% – 35%	5% – 15%

- Slow processes produce even ratio of products.
- Fast processes produce mostly liquid (bio-oil).
- Slow pyrolysis(350- 450°C):
  - Conventional, mature and well established pyrolysis process producing charcoal,
  - The technology is in the form of a kiln or retort system and the process temperatures are typically 450°C.
- Fast or Flash pyrolysis(450- 600°C):
  - Newer development of pyrolysis
  - with higher operating temperatures of 500°C but
  - an inert atmosphere of e.g. nitrogen or argon
  - with a residence time of less than two seconds and
  - rapid quenching.
  - Geared to producing liquid fuel (Bio-oil)
  - The oil can be up to 80% of the products and has a volumetric energy density of about 60% that of fossil fuel oil.
  - The bio-oil product generally has a heating value half that of conventional fuel oil.
  - It requires fairly extensive grinding to particle sizes below 6 mm,
  - It also requires drying to obtain moisture contents of 10% or lower, to minimise the water content of the liquid product.

- Pyrolysis oils can be used in modified boilers (with a start-up fuel)
- emitting lower nitrogen and sulphur oxides than with fossil fuel but higher particulate emissions.
- Bio-oil drawbacks are Physicochemical instability and consequently poor storage capabilities.
- Bio-oil has no universally accepted standard.
- High tar content increases viscosity and may damage machines.
- There are concerns about long term fouling and corrosion when using pyrolysis oil.
- Thus the oil needs to be upgraded for use in engines or other value added products.
- The oil, being a liquid, is easily pumped and stored (although consideration should be given to its high acidity).
- The oil could also be transported to a central plant for further treatment by gasification to a syngas.
- Bio-oils are rich in chemical by-products.
- Further technical development is required to reduce costs.

Comparison of second-generation thermal technologies

Table C.7: Products of thermo-chemical processing of biomass

		Liquid (%)	Char (%)	Gas (%)
Fast pyrolysis	Moderate temperature, short residence time particularly vapour	75	12	13
Carbonisation	Low temperature, very long residence time	30	35	35
Gasification	High temperature, long residence times	5	10	85

It has been shown that there are many variations on second-generation thermal processing technologies that are currently under development, and all of these have their own merits in terms of the nature of the energy products, scale, markets and available feedstock. In each case, the technology to be used will depend on the demand. (Bridgwater, 2002).

By varying the thermal processing conditions, the product spread between char, oil and gas will be varied. For example, fast pyrolysis maximises the liquid oil product, vacuum pyrolysis provides a more equal split between char and oil, and gasification favours gas formation, which can be applied in various ways. The table below presents the different modes of biomass thermal processing for different product spectrums.

Table C.8: Products of thermo-chemical processing of biomass

Process	Charcoal	Liquid	Gas
Fast pyrolysis ~500°C <2s residence time	12%	75% (mostly organics)	13%
Slow (vacuum) pyrolysis Low-moderate temp Long residence time	35%	30% (mostly H_2O)	35%
Gasification ~800°C Long residence time	10%	5% tars	85%

Source: Bridgwater, 2003

In addition, tables C.9 and C.10 summarising the typical capacities, efficiencies, investment costs and current status of thermo-chemical technologies for biomass in Europe (Bridgwater, 2002).

Bridgwater *et al*, 2002 also published economic data for thermo-chemical processing technologies.

From a life cycle point of view, it has been shown that gasification of low moisture biomass with a combined cycle is more energy- and cost-effective than direct combustion for electricity generation. In 1997 it was found that biomass gasification would reach a carbon closure of at least 94%, while the life cycle efficiency would be around 35%. Net energy ratios of 11 to 15 were calculated.

In terms of heat utilisation, gasification is also the most efficient at low moisture contents, followed closely by pyrolysis, but at high moisture contents anaerobic digestion biogas is more efficient. It was found that process thermal efficiency of the finished bio-oil product from fast pyrolysis to be around 52%, while a life cycle thermal efficiency of the finished product is around 40%.(Bridgwater, 2002).

The Following tables contains general information supporting the claims made surrounding thermo-chemical processing of biomass (Bridgwater, 2002):

Table C.9: Advantages and disadvantages of thermo-chemical processing of biomass

Technology	Advantages	Disadvantages
Combustion	• Well established and widely used • Low(er) CAPEX/OPEX • Can process a varied feedstock	• NOx reduction technologies needed • Large water consumption for electricity generation • Low(er) biomass to electricity efficiency
Gasification	• Syngas more efficient than direct combustion of the original fuel • There is a reduction of emissions relative to the combustion technology • Can be used for fuel cells	• More sophisticated than combustion • Post treatment to remove corrosive ingredients that may damage the engines • Only processes chunky feedstock • Few large scale commercial plants
Fast Pyrolysis (bio-oil)	• Oil energy between 16 - 19 MJ/kg but lower NOx / SOx than fossil fuel • Oil combustion more efficient controllable / cleaner than solid fuels • Liquid fuel and therefore is more easily pumped and stored • There is a lower cost to retrofit existing gas- or oil-fired combustion systems	• Requires small particles (therefore pre-processing of biomass) • Has a higher particulate emissions than that of fossil fuel • Oil needs upgrading to avoid long term fouling and corrosion of engines • Very few large scale plants world wide
Pellets	• Low moisture content (<10%) • Very high combustion efficiency • Regular geometry and small size allow automatic feeding with very fine calibration	• Limited market in SA therefore needs to be exported • Large water consumption for elec generation • Low(er) biomass to electricity efficiency
Slow pyrolysis (Charcoal)	• Can process a wide range of feedstock • Simple technology (especially Kiln) • Product is denser than wood with lower emissions	• High investment cost compared to output • Charcoal only a third of product

Table C.10: Specification overview of thermo-chemical processing technologies.

Global overview of current and projected performance data for the main conversion routes of biomass to power and heat and summary of technology status and deployment in the European context; based on a variety of literature sources (i.e. (van Loo and Koppejan 2002; van den Broek et al. 1996; Kaltschmitt et al. 1998; Faaij et al. 1998; DOE 1998) Due to the variability of data in the various references and conditions assumed, all cost figures should be considered as indicative

Conversion option		Typical capacity range	Net efficiency (LHV basis)	Investment cost ranges (Euro/kW)	Status and deployment in Europe
Biogas production	*Anaerobic digestion*	Up to several MWe	10–15% (electrical)		Well established technology. Widely applied for homogeneous wet organice waste streams and waste water. To a lesser extent used for heterogeneous wet wastes such as organic domestic wastes.
	Landfill gas	Generally several 100's kWe	Gas engine efficiency		Very attractive GHG mitigation option. Widely applied in EU and in general part of waste treatment policies of most countries.
Combustion	*Heat*	Domestic 5–50 KWth Industrial 1–5 MW_{th}	From very low (classic fireplaces) up to 70–90% for modern furnaces.	~100/kWth 300–700/kWth for larger furnaces	Classic firewood use still widely deployed in Europe, but decreasing. Replacement by modern heating systems (i.e. automated, flue gas cleaning, pellet firing) in e.g. Austria, Sweden, Germany ongoing for years.
	CHP	0.1–1 MWe	60–90% (overall)		Widely deployed in Scandinavia countries,
		1–10 MWe	80–100% (overall)		
	Stand alone power	20–100's MWe	20–40% (electrical)	2.500–1600	Well established technology, especially deployed in Scandinavia; various advanced concepts using Fluid Bed technology giving high efficiency, low costs and high flexibility commercially deployed. Mass burning or waste incineration goes with much higher capital costs and lower efficiency; widely applied in countries like the Netherlands, Germany etc.
	Co-combustion	Typically 5–20 MWe at existing coal fired stations. Higher for new multifuel power plants.	30–40% (electrical)	~250 + costs of existing power station	Widely deployed in many EU countries. Interest for larger biomass co-firing shares and utilisation of more advanced options (e.g. by feeding fuel gas from gasifiers) is growing in more recent years.
Gasification	*Heat*	Usually smaller capacity range around 100's kWth	80–90% (overall)	Several 100's/kWth, depending on capacity	Commercially available and deployed; but total contribution to energy production in the EU is very limited.

Table C.10: Cont: Specification overview of thermo-chemical processing technologies.

Conversion option		Typical capacity range	Net efficiency (LHV basis)	Investment cost ranges (Euro/kW)	Status and deployment in Europe
	CHP gas engine	0.1–1 MWe	15–30%	3.000–1.000 (depends on configuration)	Various systems on the market. Deployment limited due to relatively high costs, critical operational demands and fuel quality.
	BIG/CC	30–100 MWe	40–50% (or higher; electrical efficiency)	5.000–3.500 (demo's)	Demonstration phase at 5–10 MWe range obtained. Rapid development in the nineties has stalled in recent years. First generation concepts prove capital intensive.
				2.000–1.000 (longer term, larger scale)	
Pyrolysis	Bio-oil	Generally smaller capacities are proposed of several 100's kWth.	60–70% heat content of bio-oil/feedstock.		Not commercially available; mostly considered a pre-treatment option for longer distance transport.

Some key assumptions for the estimated production cost ranges are given in footnotes; generally they reflect European conditions.

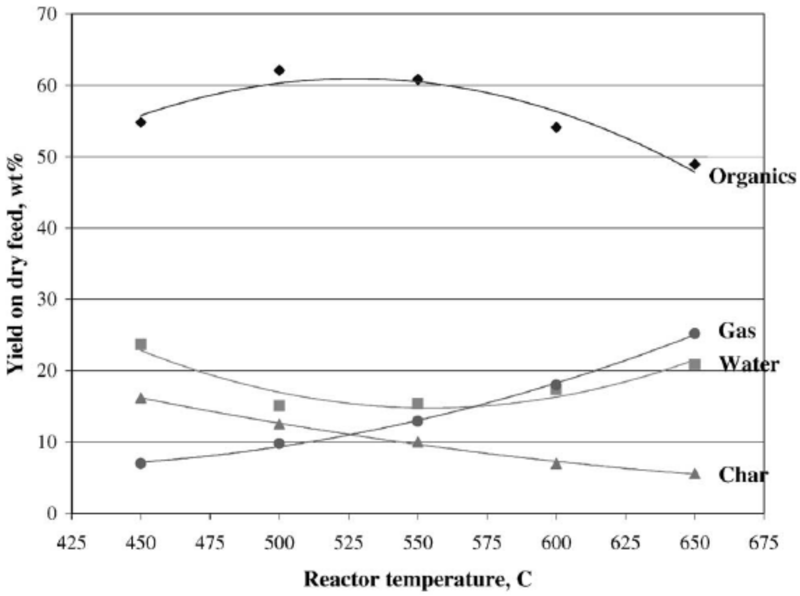

Fig.C.2: Yield to operation temperature comparison for thermo-chemical processing of biomass