Chapter 3: Analysis of existing theory

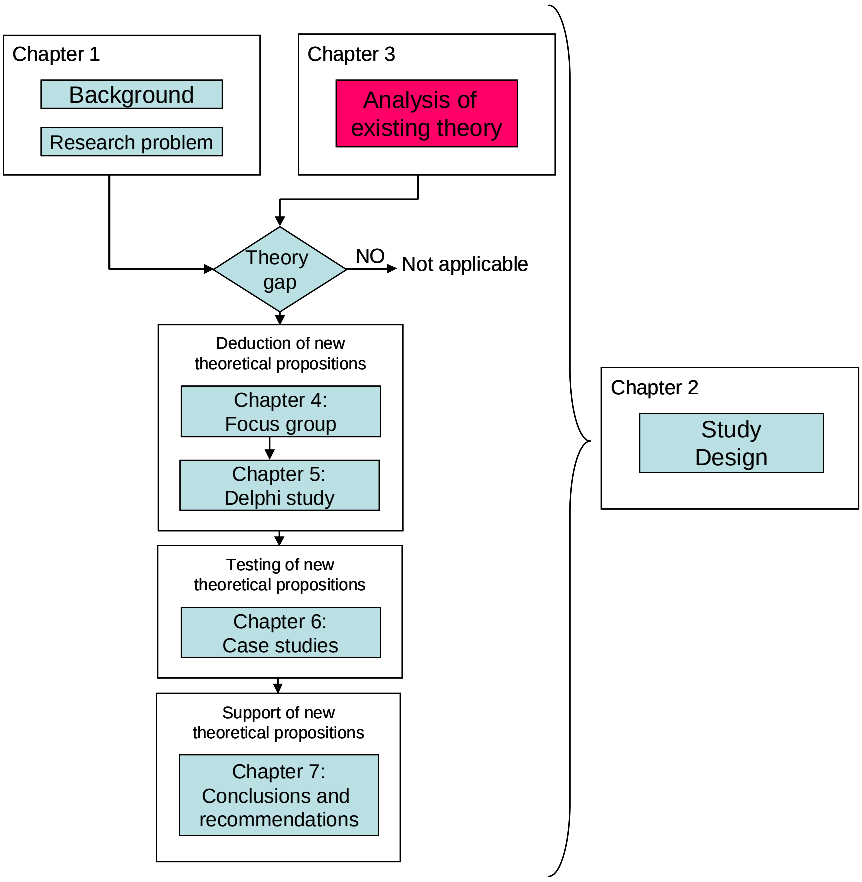

Table of contents Chapter 3

List of Figures Chapter 3

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List of Tables Chapter 3

"A nation's ability to solve problems and initiate and sustain economic growth depends partly on its capabilities in science, technology, and innovation. Science and technology are linked to economic growth; scientific and technical capabilities determine the ability to provide clean water, good health care, adequate infrastructure, and safe food. Development trends around the world need to be reviewed to evaluate the role that science, technology, and innovation play in economic transformation in particular and sustainable development in general." – (Juma and Yee-Cheong 2005)

3.1. Introduction

The majority of the population in sub-Saharan Africa lives in rural areas and most of the people spend 5% to 20% of their monthly income on fuel (Energy sector management assistance program 2006). Currently only 23.6% of the total population has access to electricity. Only 8.4% of people in rural areas in sub-Saharan Africa have access to electricity. In those rural areas where electrification has taken place, the most common uses for electricity are lighting, access to media and limited use of appliances (the main appliances are irons, colour TVs, fridge/freezers, radios and electric fans) (Energy sector management assistance program 2006). Rural Africans do not use electricity for cooking as they prefer alternatives such as gas (Energy sector management assistance program 2006).

Countries in Africa import foreign technology to improve the quality of life of their citizens, for example by importing energy technology (Dunmade 2002). The majority of these imported technologies fail because the technologies are not sustainable (Dunmade 2002). The general success rate of World Bank financed electric power projects is 68%, whereas the success rate of such projects in sub-Saharan Africa is estimated to be only 36% (Dunmade 2002). In other developing countries such as Peru, for example, it has been found that despite energy reforms electricity supply is still designed to reach rural areas (Cherni and Preston 2007). Policy changes by government administration are required for renewable energy to provide the benefits required by the end users (Cherni and Hill 2009).

Through this research an attempt has been made to determine the factors which must be taken into account for the selection of renewable energy technologies in Africa so that the implementation of technologies will be sustainable. This chapter is an analysis of the current challenges which have to be faced in introducing renewable energy technologies in sub-Saharan Africa. Renewable energy technologies are first investigated. Then follows a section on the challenges of implementing such technology in sub-Saharan Africa. Finally an analysis of the selection methodologies, measures and ratings is presented. To understand selection decision-making there is a discussion about the different types of decision making methods which have been developed and applied in project selection, portfolio selection, programme selection and technology selection. Project selection methods are mainly used to select project portfolios and programmes.

3.2. Renewable Energy Technology

"Energy supply is essential for all aspects of life, industry and commerce. A successful economy depends on both supply and use being secure, safe and efficient." (United Nations Energy Agency 2007)

Energy can be viewed as the primary driver for achieving sustainable development (International Energy Agency 2007). Energy services are required to meet basic human needs, which include the need for shelter and the need for food; energy services further improve education and health services, and contribute to human development (Cherni and Hill 2009; International Energy Agency 2004) . Renewable energy technologies have a big role to play in ensuring that the rural poor in Africa are given access to energy (United Nations Energy Agency 2007). Renewable energy technologies are developed in stages and the stage in which the technology is at the time of implementation can affect the success of failure of the implementation.

Renewable energy technologies usually progress from research and development to fully commercial applications over a period of time. First generation technologies emerged from the industrial revolution at the end of the 19th century and these technologies are in the fully commercial phase; second generation technologies are now entering the renewables market because of research and development since the 1980s; these technologies are mostly supported commercial or fully commercial; third generation technologies are still under development. These technologies are in the research and development (R&D), demonstration and pre-commercial phases (International Energy Agency 2007).

There are many types of renewable energies which are currently being used or researched as shown in Table 3-1.

Table 3-1: Summary of types of renewable energy (adapted from International Energy Agency 2007)

Category	Description	Technology generation
Combustible renewables and waste		
• Solid biomass	Organic, non-fossil material of biological origin used for heat or electricity generation.	First
• Charcoal	Solid residue of destructive distillation and pyrolysis of wood and other vegetal matter	First

Category	Description	Technology generation
• Biogas	Gases composed principally of methane and carbon dioxide produced by anaerobic digestion of biomass and combusted to produce heat and/or power.	First
• Liquid biofuels	Bio-based liquid fuel from biomass transformation, mainly used in transportation applications.	First
• Municipal waste (renewables)	Municipal waste energy comprises wastes produced by the residential, commercial and public services sectors and incinerated in specific installations to produce heat and/or power. The renewable energy portion is defined by the energy value of combusted biodegradable material.	First
• Modern forms of Bioenergy	More modern forms of bioenergy include biomass-based power and heat generation, co-firing, biofuels for transport and short rotation crops for energy feedstocks. These are more advanced and each has its own unique benefits. Biomass is attractive for use either as a stand-alone fuel or in fuel blends, such as co-firing wood with coal, or mixing ethanol or biodiesel with conventional petroleum-based fuels.	Second
• Integrated bioenergy systems	The biomass integrated gasifier/gas turbine (BIG/GT) is not yet commercially employed, but substantial demonstration and commercialisation efforts are ongoing worldwide, and global interest is likely to lead to market deployment within a few years. Overall economics of biomass-based power generation should improve considerably with BIG/GT systems as opposed to steam turbine systems.	Third
Hydropower	Potential and kinetic energy of water converted into electricity in hydroelectric plants. It includes large as well as small hydro, regardless of the size of the plants. Hydropower is an extremely flexible technology from the perspective of power grid operation. Large hydropower provides one of the lowest cost options in today's energy market, primarily because most plants were built many years ago and their facility costs have been fully amortised.	First
Geothermal		
• Geothermal power and heat	Energy available as heat emitted from within the earth's crust, usually in the form of hot water or steam. It is exploited at suitable sites for electricity generation after transformation, or directly as heat for district heating, agriculture, etc.	First

Category	Description	Technology generation
	Geothermal power plants can operate 24 hours per day, providing base-load capacity. In fact, world potential capacity for geothermal power generation is estimated at 85 GW over the next 30 years.	
• Enhanced geothermal systems	Enhanced geothermal systems, known as hot dry rock, utilise new techniques to exploit resources which would have been uneconomical in the past. These systems are still in the research phase, and require additional research, design and development for new approaches and to improve conventional approaches, as well as to develop smaller modular units that will allow economies of scale on the manufacturing level.	Third
Solar energy		
• Solar heating and cooling	Solar radiation exploited for hot water production and electricity generation. Does not account for passive solar energy for direct heating, cooling and lighting of dwellings or other. Solar thermal collectors are already widely used in certain countries, primarily for hot water production. Various technologies are becoming more widely used, such as unglazed, glazed and evacuated tube water collectors, which have market shares of 30%, 50% and 20%, respectively.	Second
• Solar photovoltaics	The photovoltaic (PV) market has grown extensively since 1992. RD&D[what's this] efforts, together with market deployment policies, have effectively produced impressive cost reductions: every doubling of the volume produced prompted a cost decrease of about 20%.	Second
• Concentrated solar power	Three types of concentrating solar power (CSP) technologies support electricity production based on thermodynamic processes: parabolic troughs, parabolic dishes and solar central receivers. Solar thermal power plants concentrate solar radiation and convert this radiation into high temperature steam which is used to drive turbines (Greenpeace 2005).	Third
• Concentrated Photo Voltaics	Concentrated PV systems utilise high concentration mirrors or lenses to focus sunlight which is captured in miniature solar cells. This technology is potentially cheap as expensive silicon cells are replaced with inexpensive optical materials such as glass, aluminium and plastic (Sustainable energy technologies 2010).	Third
• Thin film technology	Traditional solar photovoltaics use crystalline silicon wafer which is expensive. Thin film technology in the form of amorphous silicon is used as a cheaper alternative for the	Third

Category	Description	Technology generation
	silicon wafer (Solarbuzz 2010).	
Wind energy	Kinetic energy of wind exploited for electricity generation in wind turbines. Wind technology has become very reliable, operating with availabilities of more than 98% and having a design life of 20 years or more. Also, as the costs of wind turbines have steadily declined, technical reliability has increased.	Second
Tide/Wave/Ocean energy	Mechanical energy derived from tidal movement, wave motion or ocean current, and exploited for electricity generation. Over the last 20 years, ocean energy technology received relatively little research, design and development funding. However, there is renewed interest in the technology, and several concepts now envisage full-scale demonstration prototypes around the British coast. But ocean energy technologies must still solve two major problems concurrently: proving the energy conversion potential and overcoming a very high technical risk from a harsh environment.	Third

First generation technologies have been implemented in rural Africa with low rates of success (Dunmade 2002). First generation technologies such as solid biomass and charcoal are used by the majority of rural Africans but in inefficient ways.

Renewable energy can be used in residential, commercial and industrial electrification scenarios. Each sector with its requirements and possible renewable energies that can be used is shown in Table 3-2.

Table 3-2: Sector energy requirements and possible Renewable energy solutions (adapted from Prasad and Visagie 2005)

Sector	Requirements	Technology
Residential	Fuel for lighting	PV solar, wind
	Fuel for cooking	Solar cookers, wind, small hydro, gel fuel, fuel wood and other biomass
	Fuel for space heating	Wind, small hydro, biomass, solar water heaters
	Fuel for water heating	Wind, small hydro, PV solar, biomass
	Fuel for refrigeration	Wind, small hydro, PV solar, biomass
	Fuel for cooling	Passive night cooling
Commercial	Fuel for lighting	Wind, small hydro, hybrid, PV solar

Sector	Requirements	Technology
	Fuel for commercial activities	Wind, small hydro, solar
	Fuel for water heating	Wind, small hydro, biomass, solar water heaters
Industrial	Fuels for lighting	Wind, small hydro
	Fuel for industrial activities	Wind, small hydro, co

Several renewable energy technologies remain expensive compared with conventional technologies because of the higher capital costs. This means considerable initial investment and financial support for long periods before these projects become financially viable (Prasad and Visagie 2005). Further development of second and third generation renewable energy technologies will require substantial investment in terms of capital and time (Prasad and Visagie 2005). These technologies will remain too expensive for large scale implementation in rural Africa until such time as they reach the fully commercial phase.

Cooking remains one of the greatest basic needs for rural communities. It was found that where electricity is available for use by the rural poor it is mainly used for lighting, radio and television, and that electricity is too expensive to use for cooking (Prasad 2008). This means that the rural poor continue using solid biomass and charcoal, often in an unsustainable way.

A brief discussion about the unique challenges presented by conditions in Africa when selecting renewable energy technologies follows.

3.3. Challenges in renewable energy technologies in Africa

Technology management in developing countries is very different from that of developed countries. In developed countries the emphasis is on the control and utilisation of technology as well as the offsetting of the undesirable consequences of technology. In developing countries on the other hand, because of the lack of skilled resources, the emphasis is on technology selection and transfer to achieve rapid economic and social development (Ruder, *et al.* 2008). Technology transfer for sustainable development has however failed to meet expectations. According to the International Environmental Technology Centre (2004) the following elements have to be taken into account for the successful transfer of technologies:

- *Context of implementation*. A different location or stage in the technology life cycle can mean that a given technology is no longer environmentally sound.
- *Challenges*. The challenges in technology transfer are dependant on the specific application but can include insufficient innovation; performance of the

technology being not-as-expected; the enabling environment not being optimal for the technology; and lack of information.

- *Informed choice*. The users and installers of the technology must have sufficient information to make choices of the most appropriate technology.
- *Certainty of success*. Renewable energy technologies are often perceived to have high levels of risk associated with their implementation as they are believed to be unproven. Proper risk management and support of financial institutions is required to alleviate the risks.
- *Effective and efficient communication*. Effective and efficient communication is essential to ensure that key stakeholders are actively removing barriers in implementation.
- *Stakeholder capacity*. It is essential to ensure that all stakeholders have the capacity to fulfil their roles in the technology transfer chain.
- *Commitment to overcome challenges*. All stakeholders must be committed to support the technology transfer efforts.

Most of the elements which are important for successful technology transfer are also important considerations for technology selection. Various researchers have discussed the factors for the selection of sustainable energy technologies, in general, in developing countries and some have focussed on the special characteristics for the selection of technologies in Africa.

According to the findings of Teitel (1978) in his study on the selection of appropriate technologies for less industrialised countries some industrial technologies are inappropriate because of “inadequate response to market requirement; failure to use and or adapt to the local supply of materials; failure to adapt to a smaller scale of production; insufficient use of labour because of price distortions and other restrictions; import of unsuitable machinery; selection of unsuitable technology because of restriction on the acquisition of technology”. Teitel (1978) further states that the top three reasons for badly implemented technology in developing countries are maintenance and repair complexities; obsolescence of components and the fact that the technology has not been adapted to the climate.

According to Dunmade (2002) the primary factor for sustainability of a technology is adaptability of the technology, whereas the secondary factors include technical sustainability, socio-political sustainability, environmental sustainability and economic sustainability.

In the SURE model, proposed by Cherni, *et al.* (2007) for the calculation of energy options for rural communities and tested in a Columbian rural community, use is made of a multi-criteria decision support system. The SURE model includes the following factors – physical resources including houses and roads; human resources such as skills and education; financial resources including wages and savings; social resources such as networks and social organisations and natural resources including land and water resources (Cherni, *et al.* 2007).

The factors mentioned in the literature for Africa specifically are discussed in the discussion which follows. The selection of emerging technologies is complex. This makes their selection and evaluation more complex because of the inherent uncertainty and ambiguity of emerging technologies (Haung, *et al.* 2009). Many renewable energy technologies are emerging technologies. Africa is also an emerging economy, so the introduction of new technologies is complicated.

The translation of research knowledge in and of Africa into economic and social benefits is very complex (Chataway, *et al.* 2006). The complexity of the technology selection problem grows as the number of factors and the number of alternatives to consider increases (Torkkeli and Tuominen 2001).

The lack of skilled resources creates great difficulties in Africa. These difficulties are experienced by the implementing organisations, government and users. Countries in Africa do not have the institutional capacity to implement effective environmental policies; this is mainly because building institutional capacity involves the development of material and human resources and Africa does not have skilled human resources (Ebohon, *et al.* 1997). Consumers in Africa do not easily accept renewable energy technologies because they lack knowledge about the advantages and opportunities for using these energies (Prasad and Visagie 2005). Other realities in Africa (for example poverty alleviation) can derail the implementation of renewable energies as conventional energy implementation is cheaper in the short term (Prasad and Visagie 2005). When renewables are first implemented, training and knowledge transfer needs to take place which means that resources, capital and time need to be expended (Jimenez, *et al.* 2007).

To overcome these difficulties in Africa it is important that training and education of the community, especially the poor, is undertaken before technologies are implemented (Energy sector management assistance program 2006; United Nations Energy Agency 2007). Training and skills development of communities will alleviate the lack of user acceptance and also ensure that the skills base of the community can be improved to help maintain the technology (Prasad and Visagie 2005). It is important that government create consumer awareness through information programmes to educate the potential users on the advantages of renewable energy technologies (Nguyen 2007). Training of personnel and setting of technical standards also helps overcome the difficulties of the lack of skills in Africa (United Nations Energy Agency 2007).

Government participation and support is important for the success of implementation of sustainable energy technologies in Africa. Institutional and political frameworks are essential to ensure the success of implementation of renewable energy technologies. The technology selected must impact on both the priorities of the local population as well as on the social and environmental targets of the government (Cherni and Hill 2009). The implementation of legal and regulatory frameworks, policies and strategies which support renewable energy technologies needs to be backed by government (Prasad and Visagie 2005). Further there has to be a willingness by government to subsidise technologies (Prasad and Visagie 2005). In China, also a developing economy, laws have been enacted for renewable energy development but a body for enforcement has not been clearly assigned. This will hamper implementation (Cherni and Kentish 2007). Government can also encourage the implementation of renewable energy technologies by removing taxes and duties to exempt components or renewable energy technologies which are imported and establish a specialised agency to plan and promote renewable energy technologies (Nguyen 2007).

Decentralised renewable energy systems in developing countries are unattractive for customers because of the initial high investment cost which low income rural households cannot afford. In addition those households expect that the grid will be extended to their households in future (Nguyen 2007). Governments can overcome these difficulties by setting targets for renewable energy dissemination and communicating the fact that grid extension is too costly to rural communities. (Nguyen 2007). By providing subsidies government can support the financial elements of renewable technology implementation (Nguyen 2007; Prasad and Visagie 2005). Another way of offsetting costs is by arranging consumer credit (Nguyen 2007) and finally, by setting up an energy body which installs systems, retains ownership and bills for services, government can show its commitment to renewable energy usage in a community (Nguyen 2007).

When implementing renewable energy technologies in informal rural communities commonly used economic measures of development and wealth are not applicable as these measures do not make allowance for cash income, payment in kind or the provision of basic services by government (Cherni and Hill 2009). The initial and operational costs of renewable energy technologies should be subsidised by government or donor agencies to ensure that renewable energy technologies can compete with conventional technologies (Prasad and Visagie 2005). Up front communication with the community about the costs associated with the use of electricity also contributes to success of implementation (Energy sector management assistance program 2006).

Renewable energy projects should support the improvement of life of the poor and should ensure job creation for the poor (Prasad and Visagie 2005). Research in Cuba shows that the success in implementation of renewable energy technologies in rural areas is dependant on the ability of the technology to change local community livelihoods and also to protect the environment (Cherni and Hill 2009).

The involvement of the community has also been shown to be important for the success of renewable energy technology implementation. Innovative energy products first reach the early adopters who have a visionary attitude and will adopt the innovation. An innovation chasm then exists in which the innovation does not reach the rest of the population. It is suggested that mainstream members of housing associations should be persuaded to adopt energy conservation innovations to ensure that the innovations reach the rest of the population (Egmond*, et al.* 2006). Support from the community of renewable energy projects is also needed to avoid theft (Energy sector management assistance program 2006).

In brief the challenges in implementing renewable energy technologies in Africa in a sustainable way have been outlined. What follows is a summary of the main project, technology, portfolio and programme selection methods which can be used according to the literature on the topic.

3.4. The selection problem

The selection problem addressed in this research deals with fulfilling the energy requirements of Africa by selecting the appropriate energy alternative (which alternatives are shown in Table 3-1).

To make a selection decision, a list of alternatives and the factors which will be used to judge the alternatives is required. A practical example might be in order here. For example, when selecting a microwave oven to purchase one can have a list of manufacturers - *LG*, *Samsung*, *Defy* and *Panasonic*. The factors which are important in the selection of the microwave oven might be size, cost and aesthetics. Once the alternatives and factors have been decided upon, the next step is to decide how each factor will be measured. In the case of a factor such as size, the measurement is easy as the data are available. Cost however can be more complex as one can measure the cost of the microwave oven in terms of the life cycle cost - the likely cost of spares and maintenance or the cost of electricity by looking at efficiency of consumption. Aesthetics is an elusive concept to measure – it could be subjective – to fit the colour scheme of the kitchen, or it could be about the design. Then a selection methodology must be chosen to compare the different measures for each alternative in a way that will give the best answer. As can be seen from the above example, selection decision-making is not easy. Decision theory exists to give decision-makers tools to make important decisions more effectively.

Decision theory as applied in technology selection, portfolio selection, programme selection and project selection shows that the selection activity has many features in common. The methods of technology, portfolio, programme and project selection are discussed in detail next. All the methods found in the literature are discussed for completeness' sake although not all the methods discussed have direct bearing on the research.

In investigating the decision-making methodologies it becomes clear that the answer given by the methods is only as good as the framework of factors that are considered to be important for the decision. To this end, the different types of factors taken into account in different scenarios are investigated later in this chapter.

Lastly the measures used to determine ratings for factors are also investigated in this chapter. In some cases measures can be purely numerical, as for example, the power rating of the microwave oven in the exemplum above. In other cases the measure can be more subjective as is the case for the aesthetics of the microwave oven - then linguistic scales and other methodologies are used to determine the measurement.

3.4.1. Selection methodologies

A vast number of selection methods exist. The methods can be classified as economic methods; combination of economic and other methods; comparative methods; optimisation methods; strategic methods; and combination methods. Selection methods in general are discussed and then follows an elaboration on each of the methods.

A selection tool should be accessible to stakeholders, should be able to be used to evaluate investment, should include all applicable factors, should enable the use of established accounting principles and should produce results which can be verified by financial managers (Kengpol and O'Brien 2001).

Common characteristics of successful selection methodologies considered by (Torkkeli and Tuominen 2001) are shown in Figure 3-1.

Procedure •Well defined phases •Simple tools and techniques •Written records	**Project management** •Adequate resourcing •Agreed timescales
Participation •Individual and group •Workshop •Decision making leading to action	**Point of entry** •Clearly defined expectations •Ways to establish understanding agreement and commitment

Figure 3-1: Common characteristics of successful selection methodologies (Torkkeli and Tuominen 2001)

It is clear that choosing a selection methodology is not just about the method, factors, measures and ratings but also about the context in which the selection is taking place and the stakeholders involved.

An important point in developing a selection methodology is that the methodology can never completely address the complexities of the real world and will always make assumptions about the real world. The problem with the use of models is that real world issues are often ignored in an attempt to make the models less complex. A summary of the assumptions made when developing models versus the real world environment is shown in Table 3-3 (Souder 1978). The implications for this study are indicated in the last column of the table and will be taken into account when developing the framework of factors.

Table 3-3: Assumptions when Developing Models versus Real World Environment (adapted from Souder 1978)

Assumptions when developing models	Real world environment	Implications for this study
A single decision maker in a well-behaved environment	Many decision makers and many decision influencers in a dynamic organisational environment	A stakeholder analysis must be done to determine who the decision makers are and also who will influence the decisions
Perfect information about candidate projects and their characteristics; outputs, values and risks of candidates known and quantifiable	Imperfect information about candidate projects and their characteristics; outputs and values of projects are difficult to specify; uncertainty accompanies all estimates.	It must be accepted that imperfect information is available but the measures put in place must optimise the decision making process
Well-known, invariant goals	Ever-changing fuzzy goals	The long term strategy must be clear but the shorter term goals will remain fuzzy
Decision making information is concentrated in the hands of the decision maker, so that he has all the information needed to make a decision	Decision making information is highly splintered and scattered piecemeal throughout the organisation with no one part of the organisation having all the information needed for decision making.	The template for information gathering during the proposal phase must elicit the information necessary to make proper decisions
The decision maker is able to articulate all consequences	The decision maker is often unable or unwilling to state outcomes and consequences	Decision makers must be given tools that help them understand the outcomes and the consequences
Candidate projects are viewed as independent entities, to be individually evaluated on their own	Candidate projects are often technically and economically interdependent	The interdependencies between projects must be taken into account

Assumptions when developing models	Real world environment	Implications for this study
merits		
A single objective, usually expected value maximisation or profit maximisation is assumed and the constraints are primarily budgetary in nature	There are sometimes conflicting multiple objectives and multiple constraints and these are often non-economic in nature	The qualitative as well as quantitative measure of project must be taken into account
The best portfolio of projects is determined on economic grounds	Satisfactory portfolios may possess many non-economic characteristics	The qualitative as well as quantitative measure of project must be taken into account
The budget is optimised in a single decision	An iterative, re-cycling budget determination process is used	The methodology must cater for a cyclical process

Although an abundance of proposed selection techniques and lists of evaluation criteria have been reported, no consensus has emerged about an effective selection methodology (Hall and Nauda 1990). The selection of projects is a very complex problem with many factors which can and should be taken into account. It is however impossible for any model to take all factors into account (Meredith and Mantel 2003). In developing a project selection method for sustainable energy projects in Africa, the above assumptions will need to be tested against the real world environment.

Most project selection methods reported on in the literature have serious drawbacks with the central issues of concern being the uncertainty of the future business environment and the technical results of R&D (Costello 1983). Project selection methods must take into account the heuristic nature of project selection and the fact that decisions on project selection are taken at many different levels in the organisational hierarchy (Winkofsky, *et al.* 1980).

Any method proposed for the selection of sustainable energy projects should therefore take into account the following (Winkofsky, *et al.* 1980):

- *Project selection methods*. Careful consideration of the method to be used for project selection. All the existing methods have advantages and disadvantages. It may be that the best solution for this problem will be made up of a combination of some of the existing methods or that a new method needs to be developed.
- *Criteria for energy project selection*. The important criteria for energy project selection need to be determined. All methodologies are based on certain criteria which are important in specific instances with the result that even if an existing methodology is used, the criteria that are important for successful energy projects in Africa need to be considered.

- *Determination of stakeholders*. It is very important to specify the stakeholders for project selection as the attitudes and requirements of the stakeholders will have a large impact on the method and factors selected.
- *Understand the project selection cycle*. The project selection cycle over time needs to be understood to be able to decide whether the method must be applicable to periodic processes only or whether it is applicable to an ongoing process.
- *Criteria or factors*. Finally, all the methods described enable projects to be selected using specific criteria or factors.

What follows is a more detailed discussion of each of the methods.

3.4.1.1. Economic methods

Economic methods attempt to compute the cost benefit of performing a project or attempt to quantitatively assess the financial risk of performing a project (Hall and Nauda 1990). These methods are also used in technology selection (Chan*, et al.* 2000; Shehabuddeen*, et al.* 2006). The problem economic models have is that it is difficult to obtain the data, which include investment cost, gross income, expenses, depreciation, salvage value, interest rate which is required to do the calculation at the time that the technology is selected (Chan*, et al.* 2000) A summary of the economic methods with authors is shown in Table 3-4.

Table 3-4: Summary of economic methods

Methodology description	Author(s)
Payback period	Lowe*, et al.* 2000
Net present value	Cetron*, et al.* 1971; Lowe*, et al.* 2000; Martino 1995
Internal rate of return	Lowe*, et al.* 2000; Martino 1995

Payback period (PP) compares the amount of time that different projects or technologies will take to recover initial capital outlay (Lowe*, et al.* 2000).

Net present value (NPV) converts the cash flow of projects to a single value, stated in present monetary value, which makes comparisons between early and late values in the same cash flow stream possible as well as a comparison between cash flows which have different profiles of income and expenditure (Lowe*, et al.* 2000; Martino 1995). In a survey by Cetron (1971), nine of the methods that were examined utilised NPV. NPV allows for the comparison of projects in terms of their differing streams of expenses and revenues. The main difficulty in the utilisation of NPV is that cash flows for R&D projects are not very predictable. A further drawback of NPV is that an assumption is made that a constant discount rate is applicable over time (Martino 1995).

The internal rate of return (IRR) is the discount rate that would reduce the NPV of a cash flow profile of a project to zero. For the selection of projects, the greater the IRR, the better the project as it will achieve payback sooner (Martino 1995). The advantage of this method over NPV is that future interest rates need not be estimated, but just as with NPV, the future cash flows of R&D projects must be estimated (Lowe*, et al.* 2000).

The drawback of the use of economic methods alone for selection is that the identification of the economic data required at the start is often not possible and as a consequence inaccurate data are used to make the decision. Other important factors are also ignored if economic methods are used in isolation and this is treated in the discussion of the combination of economic and other methods.

3.4.1.2. Combination of economic and other methods

When combining economic and other methods, these methods still focus on the cost benefit but also take other factors into account. A summary of the combination of economic and other methods with authors is shown in Table 3-5.

Table 3-5: Summary of combination of economic and other methods

Methodology description	Author(s)
Cost benefit method	Silverman 1981
Risk analysis approach that maximises net present value	Sefair and Medaglia 2005

The cost benefit method proposed by (Silverman 1981) combines a scoring/economic approach for estimating the relative merits of R&D projects. The method requires the estimation of three vectors of economic and scoring values, i.e., energy benefits, consumer savings and societal factors. The advantage of this method is that it focuses on managerial issues but that is to the detriment of the technical project issues which are not addressed.

As an example of *a risk analysis approach*, (Sefair and Medaglia 2005) proposes a mixed integer programming method which maximises the sum of net present values of chosen projects, while minimising the risk of the projects. The method combines the project selection and sequencing decisions while considering risk and profitability as optimising criteria. The advantage of the approach is that it takes more factors into account than the NPV approach. On the other hand, the risks of R&D projects are not always easy to quantify, especially over the longer term.

The economic methods combined with other methods still have an emphasis on the economic viability of the technology or the project and are not preferred for this research study.

3.4.1.3. Comparative methods

Comparative methods compare different projects or technologies with each other by considering the important factors for selection and then using theoretical methods or simulations to select the best alternative. A summary of the comparative methodologies with author(s) is shown in Table 3-6.

Table 3-6: Summary of comparative methods

Methodology description	Author(s)
Ordinal ranking	Cook and Seiford 1982
Q-sort which is a structured psychometric communication method	Archer and Ghasemzadeh 1999; Helin and Souder 1974; Souder 1978
Pairwise comparison	Hall and Nauda 1990; Martino 1995; Mohanty 1992; Souder 1975
Electre method uses decisional scenarios for comparison	Beccali, *et al.* 2003
Scoring methods where each project proposal is scored in respect of available and determinable criteria	Archer and Ghasemzadeh 1999; Hall and Nauda 1990; Martino 1995
Analytic hierarchy process (AHP)	Bick and Oron 2005; Chan, *et al.* 2000; Firouzabadi, *et al.* 2008; Gokhale and Hastak 2000; Jimenez, *et al.* 2007; Lee and Hwang 2010a; Libertore 1987; Saaty 1990
Analytic network process (ANP)	Mulebeke and Zheng 2006
Fuzzy analytic hierarchy process	Chan, *et al.* 2000; Dagdeviren, *et al.* 2009
Rule-based expert system using interactive question and answer session with user	Masood and Soo 2002
Multi-objective evolutionary approach for linearly constrained project selection under uncertainty	Medaglia, *et al.* 2007
Weighting method using different scenarios	Chandler and Hertel 2009
Four level multi-criteria decision making method	Ruder, *et al.* 2008
Probabilistic rule-based decision support system	He, *et al.* 2006
Decision method for selecting slightly non-homogeneous technologies	Saen 2006a
Phased group decision support system	Torkkeli and Tuominen 2001

Methodology description	Author(s)
Deterministic parallel selection technique	Jeong and Abraham 2004
Profile method	Martino 1995

A brief discussion of the various methods follows. For *ordinal ranking*, each member of a committee is asked to rank a set of projects ordinally along a set of dimensions. It is then assumed that a cardinal weight is assigned to each dimension which is used to simplify the problem into a single dimension. An index indicating the degree of agreement of the committee members is given. A constrained linear assignment method is then used to allocate the relative project priorities (Bernado, 1977 as referenced in (Cook and Seiford 1982).

The ordinal ranking method is simple and easy to use. Despite the advantage of simplicity, the disadvantages include the fact that the method assumes that dimensions can all be collapsed through the use of a set of weights, which is equivalent to proposing the existence of a utility function. The method is also structured for small problems and will be cumbersome for more than 50 projects (Cook and Seiford 1982).

Q-sort is a structured group communication psychometric method for classifying a set of items according to the individual judgment of a group of persons selecting the projects. Each individual successively sorts items into preconceived categories. The anonymous scores are tallied and these tallies are then used as a starting point for open discussion (Souder 1978).

This method is a valuable procedure for facilitating scientist/scientist and scientist/manager communications within a project evaluation process as a clear indication of the opinions of the various group members is obtained (Souder 1978).

Helin (1974) reports that participants on a Q-sort experiment felt that the method was too imprecise to yield final decisions. They also felt that the process was highly subjective to personal preferences, ignorance and misunderstanding (Helin and Souder 1974). The process is cumbersome as the large number of comparisons involved has to be redone if another project is introduced (Archer and Ghasemzadeh 1999).

When using the *pairwise comparison method*, projects are compared (for example, preference for project *i* against project *i+1*, project i against project *i+2*, etc) until every pairwise comparison is explored (Hall and Nauda 1990). The most common methods for converting the comparisons into rankings are the dominance count method and the anchored scale method (Martino 1995). A more sophisticated approach which also uses pairwise comparison is discussed by (Mohanty 1992). In this approach a final acceptability index is given for each project which is used to rank the set of projects. The main advantage of pairwise comparison is that it elucidates conflicts and differential perceptions of R&D objectives. It also induces articulation of value structures and disclosures of hidden social-interpersonal conflicts (Souder 1975). The disadvantages are once again that the comparisons have to be redone if another project is introduced (Archer and Ghasemzadeh 1999) This method can result in many projects having the same ranking especially in the middle range (Martino 1995).

The *Electre method* is a multi-criteria decision making method which uses decisional scenarios (Beccali*, et al.* 2003) in the selection of renewable energy technologies in Sardinia. This method evaluates the alternatives according to certain criteria, followed by partial aggregation of preferences. Then the index of concordance under given criteria and the index of global concordance are calculated followed by the final ranking of criteria. Three decisional scenarios were used namely: environmental oriented scenario, economy-oriented scenario and energy saving and rationalisation scenario.

Scoring methods require individuals to specify the merit of each project proposal with respect to available and determinable criteria. The scores are then aggregated to determine an overall project rank. The highest ranking projects which can be performed within budget constraints are selected (Hall and Nauda 1990). Scoring methods have many advantages including simplicity of use and formulation. They can also take into account both objective and judgemental data (Martino 1995) and projects can be added and deleted without recalculating the merit of other projects (Archer and Ghasemzadeh 1999). The value of a scoring method is however based on how the decision criteria are selected, and whether these criteria are really known or based on estimates.

The *Analytic Hierarchy Process* (AHP) is conducted in two stages namely hierarchic design and evaluation (Saaty 1990). Design of the hierarchy involves structuring all the elements of the selection problem into a hierarchy. The method is based on determining weights of a set of criteria in one level of the problem hierarchy to the level just above. By repeating the process level by level, the priorities of the alternatives at the lowest levels can be determined according to their influence on the overall goal of the hierarchy (Libertore 1987). The main advantage of AHP is that it allows the R&D project selection problem to be linked to the business strategic planning process (Libertore 1987). The disadvantages are once again that the comparisons have to be redone if another project is introduced (Archer and Ghasemzadeh 1999). AHP is also extensively used in technology selection (Chan*, et al.* 2000; Jimenez*, et al.* 2007; Lee and Hwang 2010b) for example in the selection of reverse osmosis technology (Bick and Oron 2005). Firouzabadi (2008) and Gokhale (Gokhale and Hastak 2000)(2000) advocate the use of AHP together with zero-one goal programming.

Some authors criticise AHP by referring to “a lack of a theoretical framework to method decision problems into a hierarchy; use of subjective judgements in making pair wise comparisons; the use of the Eigen Vectors method for estimating relative weights and the lack of formal treatment of risk” (Choudhury*, et al.* 2006) . Another criticism of AHP is that it is only able to deal with hierarchical relationships and ignores inter-functional compatibility relationship issues (Mulebeke and Zheng 2006).

Because of these criticisms, the *Analytical network process* has been developed as an improvement on the AHP. The analytical network process takes into account intra functional relationship and deals with interdependencies amongst clusters (Mulebeke and Zheng 2006).

Because all measures of the factors to be taken into account for AHP are not always easily quantifiable, *fuzzy multi-criteria decision making* was developed to accomodate the uncertainty (Chan*, et al.* 2000; Dagdeviren*, et al.* 2009).

A *rule-base expert system* using interactive question and answer sessions with the user to input the data has also been proposed (Masood and Soo 2002) as well as a multi-objective evolutionary approach, which can be used when projects are partially funded, multiple uncertain objectives are to be met and the projects have a linear resource constraint (Medaglia*, et al.* 2007).

A *weighting method using different scenarios* addresses sub-factors or lowest level technical attributes and an overall score is determined by weighted summation and decision makers are asked to consider different scenarios of operation (Chandler and Hertel 2009).

The *four level multi-criteria decision making method* is very similar to the weighting method in which the four levels consist of identification of stakeholders, identification of current core competencies, identification of alternate technologies and selection criteria, identification of functions and weights for criteria as well as assessment of alternatives (Ruder*, et al.* 2008).

A *probabilistic rule-based decision support system* which is automated, takes into account domain knowledge and uses a Bayesian network to recommend the best technology as well as provide a measure on the reliability of the answer (He*, et al.* 2006).

The *decision method for selecting non-homogeneous technologies* can be used when not all the technologies under consideration consume common inputs to produce common outputs (Saen 2006a). The missing values for the technologies which have different inputs or outputs are calculated in this method.

The phased group decision support system has the following phases to select technologies - mapping and classification of factors; determination of the most important factors; assessment of alternatives, analysis of results of selection, analysis of impact of results of selection (Torkkeli and Tuominen 2001).

The *deterministic parallel selection technique* has the following key features: decisions are based on knowledge of the problem; input values to the method are crisp and tangible; parallelism exists among criteria and the tool enables its users to propose alternatives (Jeong and Abraham 2004).

In the *profile method* thresholds are set for different project characteristics for example cost, market share, market size and probability of success. Projects that fall below the preset thresholds are automatically rejected (Martino 1995).

Comparative methods are the most applicable to this study of all the methods discussed to date. These methods enable the consideration of multiple factors and as discussed in paragraph 3.3 multiple factors need to be considered in the African scenario.

3.4.1.4. Optimisation methods

Optimisation methods seek to optimise some objective function or functions subject to specified resource constraints. Various authors use a number of objective functions, which are normally economically based, and different constraints to formulate the project selection problem. These methods are conceptually attractive as they optimise specific quantitative measurements of R&D performance subject to budget and organisational constraints. Surveys have however shown that these methods are not very widely used (Archer and Ghasemzadeh 1999). A summary of optimisation methods with authors is shown in Table 3-7.

Table 3-7: Summary of optimisation methods

Methodology description	Author(s)
Integer programming	Cook and Seiford 1982
Multi-objective binary programming method which optimises project scheduling	Carazo, *et al.* 2009
Multiple test framework	Chapman, *et al.* 2006
Fuzzy R&D portfolio selection method	Wang and Hwang 2007
Fuzzy regression and fuzzy optimisation method	Sener and Karsak 2007
Mathematical programming where both ordinal and cardinal data is available	Saen 2006b

Various types of optimisation methods exist including integer programming, linear programming, non-linear goal programming, non-linear dynamic programming and a multiple test framework.

Integer programming consists of an optimization where the variables may only take integer values, i.e. 0,1,2,3,... .

A value v_l is assigned to each project l. The cost c_l of funding that project is determined. The binary knapsack problem must then be solved:

Maximise $\sum_{l=1}^{L} v_l \quad x_l$ Subject to $\sum_{l=1}^{L} c_l \quad x_l \leq B$ x_l = 0 or 1

where B is the available budget. x_l = 1 implies that the project l is funded (Cook and Seiford 1982).

The advantage of this method is that it is a very simple integer programming problem to solve. The drawback is that the values and costs are not always available in an objective way and the degree of preference for one project versus another needs to be expressed. In many cases it is unrealistic (Cook and Seiford 1982).

The other programming techniques all have similar formulas which can be solved using a computer programme.

A *multi-objective binary programming method* is proposed by (Carazo*, et al.* 2009) for the selection of project portfolios which takes into account organisational objectives. These objectives are often in conflict with each other as well as optimal project scheduling which makes for allowance of uneven availability and consumption of resources.

The *multiple test framework* proposed by (Chapman*, et al.* 2006) consists of a traffic light process where individual projects are submitted to six tests, each of which has a simple traffic light outcome. If a project gets a green light for all six measures it is accepted. A red light on any of the measures means immediate disqualification. A project with one or more orange lights is reconsidered at the next planning phase.

This method allows for more criteria than purely NPV to be taken into account. For marginal and complex choices however the review process becomes a lot more difficult (Chapman*, et al.* 2006).

The *Fuzzy R&D portfolio selection method* uses fuzzy set theory to convert fuzzy project information into a crisp integer programming mathematical method which selects projects from a risk averse perspective (Wang and Hwang 2007).

The *fuzzy regression and fuzzy optimisation method* use fuzzy regression to assess relationships between factors and non-symmetric triangular fuzzy coefficients to deal with the vagueness that cannot be modelled with symmetric fuzzy coefficients (Sener and Karsak 2007).

The *mathematical programming method using both ordinal and cardinal data* measures qualitative data on an ordinal scale for inclusion in the mathematical process (Saen 2006b).

The optimisation methods are on the whole complicated to apply and for that reason were not considered for this study.

3.4.1.5. Strategic methods

Various strategic planning methods are discussed in the literature. These methods allow allocations of resources to multiple organisational elements, organisational constraints and resources as well as multiple time periods are considered. The methods are limited to use in periodic processes. A summary of strategic methods with authors is shown in Table 3-8.

Table 3-8: Summary of strategic methods

Methodology description	Author(s)
Cluster analysis	Lee and Song 2007; Martino 1995
Decision tree diagramming	Martino 1995
Decision process methods	Martino 1995
Matrix analysis	Singh 2004
Fuzzy consistent matrix	Haung, *et al.* 2009
Quality function deployment matrix	Kim, *et al.* 1997; Lowe, *et al.* 2000
Systems approach: R&D risk and scientific merit	Costello 1983
Authority activity method	Bergman and Buehler 2004
Iteration between requirements and project selection	Bergman and Mark 2002
Interactive project selection method	Archer and Ghasemzadeh 1999; Martino 1995
Life cycle engineering method	Pecas, *et al.* 2009
Portfolio method for strategy and selection	Phaal, *et al.* 2006
Technology roadmap	Shenbin, *et al.* 2008
Systems approach	Bergman and Mark 2002; Costello 1983
Benefit, resource and technical interdependency method	Santhanam and Kyparisis 1996
Options theory and mean variance theory method	Wu and Ong 2008
Digraph and matrix method	Rao and Padmanabhan 2006

These methods are discussed in more detail in the sections that follow. *Cluster analysis* focuses on selecting projects which support the strategic positioning of an organisation. In essence the list of projects is taken and clustered together in a hierarchy according to their degree of similarity. A cluster or clusters of projects are then funded which support the organisational strategy (Martino 1995). The main advantage of this method is that clusters which support the most important objectives of the organisation are funded (Martino 1995). On the other hand funding all the projects in one cluster and not funding the other clusters may mean that the organisation can lose competitive advantage which could be obtained with a more balanced portfolio.

Decision tree diagramming can be used for project selection when the decision maker is faced with a series of projects to choose from and with chance outcomes following each choice. At the end of the sequence of choices and chances some payoff will be achieved (Martino 1995). The advantage of this method is that decision tree theory can be used to prune the branches of the tree, which guides the decision maker as to which choice will achieve the highest expected value. Further, decision trees are simple to use and can be easily incorporated in a spreadsheet. The disadvantage of this approach is that the probability of the possible outcomes has to be known with a reasonable degree of certainty (Martino 1995).

The *decision process methods* are the most sophisticated techniques which have been developed for project selection and resource allocation. These methods have been proposed by (Mandakovic and Souder 1985). They are based on a hierarchical organisation involving multiple divisions in the decision process.

The *fuzzy consistent matrix methodology* uses technology fore-sighting as an evaluation indexing system consisting of a fuzzy consistent matrix to select technology (Haung*, et al.* 2009).

The *quality function deployment matrix* is used to identify customer requirements, technical requirements and future services. A planning matrix, technology and interrelationship matrix is then prioritised to set technical targets (Kim*, et al.* 1997; Lowe*, et al.* 2000).

The *systems approach considering risk and scientific merit* is a multi-hierarchy approach as senior management determines and ranks the priorities, middle managers and research staff generate the proposals and middle management evaluate the proposals according to the priorities set by senior management (Costello 1983)

NASA use an *authority-activity method* for the selection of technologies for the new millennium programme (Bergman and Buehler 2004) which combines organisational authority and procedural activities required during technology selection.

Another systems approach consists of *iterations between requirements and project selection* to select a portfolio of projects (Bergman and Mark 2002).

The *interactive project selection method* on the other hand follows an iterative process between project managers and decision makers until the best projects are selected (Archer and Ghasemzadeh 1999; Martino 1995).

The *life cycle engineering method* compares the performance of technologies over the life cycle of these technologies in three independent dimensions namely, economic; technical and environmental (Pecas*, et al.* 2009).

The *portfolio method for strategy and selection* assesses and manages the risks, competence, business benefit, supporting strategy, benchmarking, assessment and auditing of technology portfolios (Phaal*, et al.* 2006).

Technology can also be selected by using a *technology roadmap* which gives a time-phased view of the relationship between products and markets (Shenbin*, et al.* 2008).

In the Costello (1983) *systems approach* attempts to gather the existing information from different parts of the organisation in a systematic way. Different parts of the organisation assess R&D risk and scientific merit is specifically evaluated (Costello 1983).

The Bergman (2002) *systems approach*, selects projects using an iterative process between requirements analysis and project selection. The advantages in following a systems approach are that there is normally a strong commitment to research projects selected, the important differences in the alternative research proposals are highlighted and the approach is relatively simple. The main disadvantage is the time that must be spent in meetings to reach consensus.

The *benefit, resource and technical interdependency method* identifies and models benefits, resources and technical interdependencies among candidate projects (Santhanam and Kyparisis 1996).

Project selection method using *options theory and mean variance theory* maps projects according to probability of success and uncertainty of risk of the investment. Different portfolios are then drawn up, given probability and risk which can then be used by decision makers to select the optimal portfolio of projects (Wu and Ong 2008).

The *digraph and matrix method* uses a digraph to determine the relative importance between factors and then a matrix to calculate the selection index (Rao and Padmanabhan 2006).

The strategic methods are relatively complex to apply. In the African context decision makers do not necessarily have the required skills to apply the more complex methods and for this reason were not considered for this study.

3.4.1.6. Two phase methods

Several two phase methods exist in which selection of projects and technologies are done in two phases. These methods normally apply two filters to the selection process and one or both of the filters can be one of the methods already discussed. A summary of the two phase methods with author(s) is shown in Table 3-9.

Table 3-9: Summary of two phase methodologies

Methodology description	Author(s)
Practical technology selector	Shehabuddeen*, et al.* 2006;;
Multi-attribute theory and probabilistic network method	Bard and Feinberg 1989
Data envelopment analysis and multi-attribute decision theory method	Khouja 1995
Filter system for technology selection	Yap and Souder 1993

The *practical technology selector* uses two filters, namely, technology selection requirements and technology adaption (Shehabuddeen*, et al.* 2006).

The *multi-attribute theory and probabilistic network method* first ranks and eliminates inferior technologies and then assigns resources using a probabilistic network which is solved using Monte Carlo simulations (Bard and Feinberg 1989).

The *data envelopment analysis and multi-attribute decision theory method* first identifies which technologies are the best solution for the problem from vendor specification and then uses a multi-attribute decision making method to select the most appropriate technology (Khouja 1995).

The *filter system for technology selection* first eliminates the technologies which do not support the missions, capabilities and environment of the organisation and then uses a utility method with linear programming to select the technologies to be funded based on the available resources (Yap and Souder 1993). A two filter approach was contemplated for this study as the first filter excludes the worst fit technologies and in that way simplified the decision making problem.

3.4.1.7. Combination methods

Combination methods combine the methods already discussed in this section. Several methods are discussed in the literature which combine the methods already discussed.

Table 3-10 illustrates through a matrix what the methods are which have been discussed and showing who the authors of the methods are. The matrix shows various methods (already discussed in paragraph 3.1.4.3) in the first column and in the first row. The authors that have used a combination of methods are then indicated in the row and column where the methods that they combine intersect.

Table 3-10: Combination of methodologies by author (s)

	AHP	Fuzzy AHP	ANP
Delphi	Prasad and Somasekhara 1990;		Kengpol and Tuominen 2006
Fuzzy Delphi	Shen, *et al.* 2009 plus patent co-citation	Hsu, *et al.* 2010	
Goal programming	Yurdakul 2004		Lee and Kim 2000
Cost benefit and statistical analysis	Kengpol and O'Brien 2001		
Mixed integer programmeming	Malladi and Mind 2005		
Fuzzy replacement analysis	Tolga, *et al.* 2005		

As most of these combination methods are based on comparative methods they can be considered for this research.

3.4.1.8. Ad hoc methods

Ad hoc methods are those methods that do not readily fall into one of the categories described above. There are several ad hoc methods that are referred to in the literature. Some of these methods include profiles, interactive selection and the genius award method. A summary of the ad hoc methods with author(s) is shown in Table 3-11.

Table 3-11: Summary of ad hoc methods

Methodology description	Author(s)
Profile method	Martino 1995
Interactive project selection method	Archer and Ghasemzadeh 1999
Genius award method	Hall and Nauda 1990

To use the *profile method*, each project is given a score on each of several characteristics, for example cost, market share, market size, and probability of success. For each characteristic a preset threshold is set. If the characteristics of a project fall below the preset cut-off the project is rejected (Martino 1995). The advantages of this method are that profiles are easy to display and are an effective starting point for negotiations on thresholds. Profiles are also an effective means for reporting to higher management since profiles directly show the effects of each threshold. Profiles however do not always deliver the optimal solution.

For the *interactive project selection method*, an interactive and iterative process is followed between project champions and responsible decision makers until a choice of the best projects is made (Archer and Ghasemzadeh 1999). According to (Martino 1995) this has the advantage that the selection criteria become better and better as the process proceeds. On the other hand (Martino 1995) states that if the objectives are too narrowly defined at the outset, many potential rewarding projects will never be proposed.

The *genius award method* simply provides funding to proven researchers to work on any project of their choice (Hall and Nauda 1990). The advantage of this method is that researchers are motivated to deliver because they are working on their favourite subject. The disadvantage is that strategic objectives and planning are not necessarily taken into account.

The ad hoc methods discussed above were not considered further in this study as these methods do not address multiple factors.

The paragraph that follows addresses the framework of factors that was developed in this study.

3.4.2. Framework of factors

The selection of technologies and projects is a complex problem as can be seen from the plethora of selection methods available. Each of these selection methods attempts to select the best alternative from a large number of alternatives to give the best long term solution for the problem. Each of the selection methods further uses a list, set or framework of factors as an input. This section explores how a framework of factors is designed.

Technology selection should focus on factors which can be collected and enforced objectively, and business-related criteria are important (Ahsan 2006). It is therefore important to have factors which can be easily collected and objectively measured.

Various descriptions are used to distinguish factors that can be numerically measured from those which cannot in literature. These include objective and subjective (Chan*, et al.* 2000); quantitative and qualitative (Bick and Oron 2005); and economic and non-economic (Bhavaraju 1993). The problem with objective, quantitative or economic factors is that absolute values for these factors are not always available during the selection phase and also these factors do not give the entire picture.

As with dropping a pebble in a pond, the selected technology does not only influence the project which it is selected for but also the business environment and the external environment as shown by the concentric circles in Figure 3-2. Technologies have certain factors which influence their success or failure, these are shown in the pink circle; technologies need to succeed in order to positively influence factors in the business environment, these are shown in orange; finally technologies have to operate successfully in an external environment in order to positively influence influence factors in this environment.

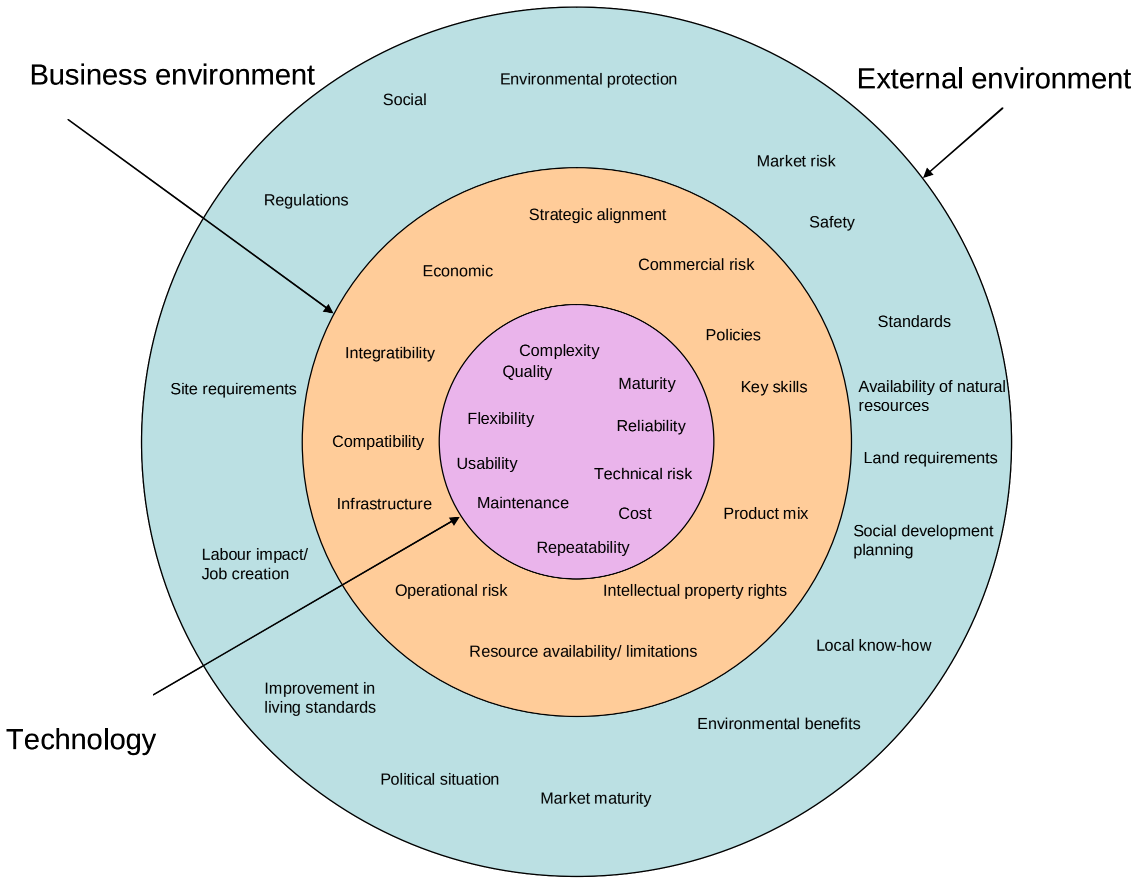

Figure 3-2: Summary of generic technology selection factors from the literature

The ultimate success or failure of technology is not only dependent on the factors related to the technology but is also influenced by factors in the business environment and the external environment. Furthermore the choice of technology is influenced by the environment and the environment is influenced by the technology.

Various authors (Beccali, *et al.* 2003; Bhavaraju 1993; Bick and Oron 2005; Chan, *et al.* 2000; He, *et al.* 2006; Lee and Hwang 2010b; Shehabuddeen, *et al.* 2006) discuss factors to take into account for the selection of technologies in specific applications. A summary of these factors at a generic level is shown in Figure 3-2. These factors are seen to be generic at this stage as they have been gathered from the above authors from different application areas. The purpose of this study is to determine which of these factors are cardinal to the selection renewable energy projects in Africa.

Ultimately all these generic factors will have an influence on renewable energy technology selection in Africa. The purpose of this study is to determine a framework of the most essential factors to ensure the long term impact of sustainable energy technologies in Africa and in that way provide decision makers with a tool for selecting factors.

3.4.3. Basket of measures

A basket of measures is required to measure each factor in the framework. There are various ways in which factors can be measured. Whether the measure of a factor is numeric or non-numeric is dependent on the type of factor. For non-numeric factors several methods of rating are used:

Linguistic scales. Qualitative linguistic scales can be used to to assign a rating to a factor (Beccali*, et al.* 2003; Jeong and Abraham 2004; Lowe*, et al.* 2000; Masood and Soo 2002; Pecas*, et al.* 2009; Prasad and Somasekhara 1990). An example of a linguistic scale is: "Very applicable", "Applicable", "Not applicable", "Certainly not applicable". Linguistic scales are sometimes converted into triangle fuzzy numbers (Chan*, et al.* 2000).

Weighting. A weight is assigned for each factor and a total weighted score calculated for each alternative (Haung*, et al.* 2009; Hsu*, et al.* 2010; Shehabuddeen*, et al.* 2006).

Pair-wise comparison. Saaty's fundamental scale for pair-wise comparison can be used to determine the relative weight of each factor (Bick and Oron 2005; Lee and Hwang 2010a; Luong 1998; Malladi and Mind 2005).

3.5. Conclusion

The implementation of renewable energy technology in Africa is required to improve the quality of life of the people in Africa. There are many benefits to the introduction of renewable energy technologies.

Several selection methodologies have been developed for both project and technology selection. The effectiveness of these methodologies is dependent on the framework of factors used to populate the selection methodology.

In the theory gap portrayed in Figure 1-6, the framework of factors for the implementation of renewable energy technologies in Africa, does not exist and the purpose of this study was to develop an appropriate framework and obtain empirical support for the framework.

Chapters 4 to 6 which follow cover the focus group, Delphi and case study research done to develop the required framework.