An Economic Analysis of Concentrator Photovoltaic Technology Use in South Africa: A Case Study

By

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Submitted in fulfilment of the requirements

for the degree of Magister Commercii (Economics) in the

Faculty of Business and Economic Sciences at the Nelson Mandela Metropolitan University

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January 2013

DECLARATION

I, Justin Beukes (Student Number: 204005035), hereby declare that this thesis for Magister Commercii (Economics), is my own work and has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

Justin Beukes

ACKNOWLEDGMENTS

I would like to thank and acknowledge the following individuals and institutions for their support and contributions towards this research project:

• Professor M du Preez, my supervisor at the Nelson Mandela Metropolitan University (NMMU), for his direction and guidance;

• Professor EE van Dyk, my co-supervisor at NMMU, for his assistance with all technical matters relating to the study;

• The Centre for Renewable and Sustainable Energy Studies (CRSES) at the University of Stellenbosch for their financial support;

• Mr. R. Pardell, at Valldoreix Greenpower, renewable energy consultants, for providing cost data for the systems;

• Mr. D. Maliti, an alternative energy manager at ASGISA Eastern Cape, for his help with locating a suitable study area, and for arranging meetings with local authorities;

• The Ngqushwa Local Municipality, for providing household data for the Tyefu area;

• Mr. C. Purcell, director of Energy and Development Group, for providing data on Eastern Cape household energy use;

• Mr. J. Goosen, at Reclam, for providing data on recycling;

• Ms. J. Emery, Controller - Internal Sales at DB Shenker, for assisting with transportation data;

• Mr. T. Vink, from the Zoology Department at NMMU, for his Geographic Information Systems (GIS) expertise in drawing up the study area map;

• Mrs. D. du Preez, from the Economics Department at NMMU, for her assistance with the labour data, and finally;

• My family for their continued patience and support during the writing of this thesis.

Justin Beukes

January 2013

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LIST OF ABREVIATIONS

BCR - benefit cost ratio

CBA - cost-benefit analysis

CE - cost-effectiveness

CEA - cost-effectiveness analysis

CIF - cost-insurance-freight

CM - choice modelling

CPV - concentrator photovoltaic

CVM - contingent valuation method

DME - Department of Minerals and Energy

DNI - direct normal irradiance

EIA - economic impact assessment

FOB - free-on-board

GHGs - greenhouse gases

HP - hedonic pricing

HPM - hedonic pricing method

IPCC - Intergovernmental Panel on Climate Change

IPPs - Independent Power Producers

IRR - internal rate of return

kWh – kilowatt hour

kWh/m$^{2/}$day – kilowatt hours per square meter per day

kWp - kilowatt peak

LPG - liquefied petroleum gas

MSB - marginal social benefit

MSC - marginal social cost

MWh – megawatt hour (=1000kWh)

NERSA - National Energy Regulator of South Africa

NPV - net present value

PV - photovoltaic

REFIT - Renewable Energy Feed In Tariff

RUM - random utility model

SOCC - social opportunity cost of capital

STPR - society's time preference in consumption rate

TCM - travel cost method

UNIDO - United Nations Industrial Development Organization

$Wh/m^{2/}day$ – watt hours per square meter per day

WTA - willingness to accept

WTP - willingness to pay

EXECUTIVE SUMMARY

South Africa relies heavily on fossil fuels, particularly coal, to generate electricity and it is a well known fact that the use of fossil fuels contributes to climate change, as it produces greenhouse gases (GHGs). In fact, internationally South Africa is the 17th highest emitter of GHGs (Congressional Research Service (CRS), 2008). Coupled with the environmental consequences of fossil fuel use, South Africa has a further responsibility of addressing the inherited backlog of electricity provision to the rural, and previously disadvantaged communities.

In an attempt to address these two problems, the government issued the White Paper on Renewable Energy. In this paper, renewable energy alternatives are proposed to replace a portion of traditional electricity generating methods.

Concentrator photovoltaic (CPV) energy generation is one such renewable option available to government. CPV uses optic elements (such as lenses) to concentrate sunlight onto solar cells. Owing to the light being concentrated, the cells in CPV use less semiconductor material, which makes them more efficient in comparison to conventional photovoltaic (PV) cells. CPV is a technology that operates well in regions with high solar radiation. As such, South Africa is particularly well suited for this technology, with average solar radiation levels ranging from 4.5 to 6.5 Wh/m^2 . CPV is also well suited for off-grid application, which addresses electricity demand in remote rural areas.

This study is an economic project analysis of the installation, operation, maintenance, and decommissioning of CPV technology in a rural area in the Eastern Cape, South Africa. The study area chosen for this purpose is the Tyefu settlement in the Eastern Cape. Tyefu was deemed ideal for this type of analysis due to four characteristics. Firstly, Tyefu is a remote rural settlement at the end of the national grid. Secondly, the community is very poor and previously disadvantaged. Thirdly, many households are without Eskom generated electricity. Lastly, the study area is located in an area with ideal irradiance levels for CPV.

Two methods of economic project analysis are applied to this case study, namely a cost-benefit analysis (CBA) and a cost-effectiveness analysis (CEA). Additionally, two types of CBA are performed, namely a private CBA and a social CBA. The private CBA evaluates the Tyefu electrification project from a private investor's perspective and the social CBA

evaluates the project from society's point of view. The CEAs carried out compare the cost-effectiveness of the traditional PV technology to that of CPV in terms of private and social costs.

The private costs and benefits of the CPV project were identified and valued in terms of market prices. Then, this cost benefit profile was used to calculate net benefits which in turn were discounted to present values using a private discount rate of 6.42 percent. Three decision making criteria were generated, namely the net present value (NPV), the internal rate of return (IRR) and the benefit cost ratio (BCR). Sensitivity analysis was carried out by varying the private discount rate and the bidding price.

The social costs and benefits of the CPV project were identified and valued in terms of shadow prices. This cost benefit profile was used to calculate net benefits. The net benefits were discounted to present values using a composite social discount rate equal to 5.97 percent. The same decision making criteria used in the private CBA were used in the social CBA and a sensitivity analysis was completed by varying the social discount rate.

In terms of the private CEA, the costs were identified and valued in terms of market prices. All costs were brought to present values using the private discount rate of 6.42 percent.

In terms of the social CEA, the costs were identified and valued in terms of shadow prices. All costs were brought to present values using the social discount rate of 5.97 percent.

The cost-effectiveness (CE) ratios calculated have identical denominators since the annual output for both technologies are identical - both CPV and PV systems deliver 30 300 kWh per annum. This output is based on the demand of the given case study.

The private CBA showed unfavourable results. The private CBA has a NPV of R2 046 629.01, the IRR is undefined (this is due to no sign change being present in the cost benefit profile), and has a BCR of 0.365. However, the social CBA yielded positive results, with a NPV of R125 616.64, an IRR of 8 percent (which exceeds the social discount rate of 5.97 %), and a BCR of 1.045.

The CEA showed that the CPV is more cost-effective than the traditional PV both in terms of private and social costs. The private CE ratio of CPV is R4.23/kWh compared to PV's CE ratio of R4.39/kWh. Similarly, the social CE ratio of CPV is R3.51/kWh compared to PV's CE ratio of R3.69/kWh.

CPV rollout appears to be socially efficient on a small scale according to the social CBA. Consequently, the CPV project is not seen as desirable in terms of the private CBA as the benefit (income received per kWh) in the private analysis is too small to outweigh the costs of implementing and running a CPV plant in Tyefu. On the other hand, a redeeming factor is that CPV may be feasible privately, for large scale applications.

A major reason for the CPV project not being appealing to private investors is that the maximum bidding price of R2.85/kWh (as at August 2011) is not high enough for private investors to undertake the CPV project. The sensitivity analysis of the bidding price showed that the bidding price of R2.85/kWh needs to be increased in the range of 250 percent (R7.13/kWh) and 300 percent (R8.55/kWh) for a great enough incentive to exist for private investors. It is thus recommended that policymakers take this into consideration when formulating policy.

In terms of the social CBA, it is recommended that government undertake CPV projects of this kind, as it will be a socially desirable allocation of resources. If government were to pursue these types of projects, it is recommended that CPV be implemented as it is more cost effective than PV.

Keywords:

Cost-benefit analysis, cost-effectiveness analysis, social discount rate, concentrator photovoltaics, photovoltaics.

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND TO STUDY

Two distinct challenges pertaining to electricity provision are facing policymakers in South Africa. First, the dominance of fossil fuel use (mainly coal) in generating electricity and its concomitant impact on the environment in terms of climate change. Second, the inherited backlog of electricity provision rollout to many, mostly rural, previously disadvantaged communities. Currently, coal is the most widely used fuel worldwide, accounting for around 36 percent of the total fuel consumption of the world's electricity production (Department of Minerals and Energy (DME), 2010). Not unlike many other developing countries, South Africa’s energy supply is dominated by the use of fossil fuels (approximately 90% of all energy generated), where approximately 77 percent is generated using coal (DME, 2003). Because of this excessive use of fossil fuels, the world is faced with the environmental damage that their use is causing.

According to the Intergovernmental Panel on Climate Change (IPCC), global climate change is primarily a result of the global pattern of energy consumption (Bradford, 2006). Approximately 85 percent of the GHGs, which lead to climate change, arise from the burning of fossil fuels. An example of a GHG is carbon dioxide. Coal emits significantly more GHG’s than oil or natural gas for an equivalent amount of energy (Bradford, 2006).

South Africa is the largest emitter of GHG's in Africa, and is amongst one of the largest contributors in the world (DME, 2003). Internationally, South Africa ranks 17 in the top twenty emitters of GHGs (CRS, 2008).

South Africa, which is considered a developing country, currently faces no external pressures to tackle the reduction of GHG emissions. According to the Kyoto Protocol, which South Africa signed, non-Annex 1 countries (developing countries) are not obliged to commit to any of the emission targets in the first commitment period, from 2008 to 2012 (Prasad, 2007). However, environmental awareness is a growing international phenomenon and the negative impacts of traditional fossil-based energy cannot be ignored. In addition, South Africa is required to meet emissions targets post-2012.

Compounding to the coal dominant and environmental issues related to electricity provision, South Africa also faces the challenge of providing electricity to the poor. Early electrification was based on the spatial and socio-economic characteristics of the Apartheid state. Access to the energy utility was developed according to racial lines, with rapid electrification of 'white' households in the first part of the Twentieth Century. Non-white urban and rural areas were excluded from the electricity infrastructure development that took place before and during Apartheid. The political transition in the 1990s led to a considerable electrification programme being advanced and financed by Eskom (a parastatal and the main provider of electricity in South Africa). This resulted in an estimated electrification rate of 30 percent in 1990 to a current rate of 75 percent (Winkler and Marquard, 2008). However, almost half (49.7%) of the South African people in rural areas live without electricity (Prasad and Visagie, 2005).

Table 1.1 gives an indication of the state of electrification in South Africa at the end of 2002. According to Table 1.1, 49.7 percent of rural people had no access to electricity, whereas only 20.2 percent in urban areas had no access.

Table 1.1: State of Electrification at the end of 2002

Province	Type of household	Households electrified	Households not electrified	Percentage electrified	Percentage not electrified
Eastern Cape	Rural Urban	351 856 553 293	588 889 27 885	38.2 95.2	61.8 4.8
Free State	Rural Urban	122 231 436 796	118 756 87 771	50.7 83.3	49.3 16.7
Gauteng	Rural Urban	38 466 1 649 705	95 576 605 813	28.7 73.1	71.3 26.9
KwaZulu Natal	Rural Urban	365 252 816 084	575 061 371 168	38.8 68.7	61.2 31.3
Limpopo	Rural Urban	610 581 157 970	385 803 3 290	61.3 98.0	38.7 2.0
Mpumala -nga	Rural Urban	294 937 261 161	144 166 52 450	67.2 83.3	32.8 16.7
Northern Cape	Rural Urban	57 448 121 417	31 990 30 276	64.2 80.0	35.8 20.0
North West	Rural Urban	305 669 358 464	239 015 37	56.1 100.0	43.9 0.0
Western Cape	Rural Urban	85 484 870 173	45 425 143 292	65.3 85.9	34.7 14.1
Total	Rural Urban Total	2 231 924 5 225 063 7 456 987	2 204 680 1 321 982 3 526 663	50.3 79.8 67.9	49.7 20.2 32.1

Source: Prasad and Visagie (2005)

In the White Paper on Renewable Energy, the South African Government committed itself to providing renewable energy for rural communities isolated from the national electricity grid, and to develop a framework within which the renewable energy industry can operate and grow in order to impact the global environment positively (DME, 2003). Renewable energy, according to the DME (2002), is defined as energy that is harnessed from naturally occurring non-depletable sources of energy, such as solar, wind, biomass, hydro, tidal, wave, ocean current and geothermal sources. Included in this paper is South Africa's intention to develop and produce electricity, gaseous and liquid fuels, heat or a combination of these energy types locally.

In order to encourage renewable energy growth, the National Energy Regulator of South Africa (NERSA) announced the regulatory rules, together with the commercial terms, of Phase I for the Renewable Energy Feed In Tariff (REFIT) on 26 March 2009. The REFIT was adopted to serve as an incentive for private companies to invest in utility infrastructure and electricity production. These private companies are also known as independent power producers (IPPs[1]).

After problems, with over-regulation and lack of standardised power purchase agreements were experienced with the REFIT framework, it was eventually abandoned in 2011 in favour of a competitive pricing framework. According to the latter, private investors must submit prices for renewable electricity provision as part of a tender process. The submitted price is subject to a given ceiling per technology, and must be equal to or below this ceiling.

Five technologies, namely biomass, wind, solar and small-scale hydro are considered viable renewable energy options in South Africa. One of the most prominent of these sources is solar energy. The reason solar radiation is favoured as a source for the generation of electrical energy is that solar systems do not pollute and there is an abundance of solar resource in South Africa (Banks, 2005). More specifically, as seen in Figure 1.1 below South Africa experiences some of the highest levels of solar radiation globally (Banks, 2005).

[1] IPPs finance and construct power plants. A power purchasing agreement (PPA) is set up between the buyer (local municipalities and authorities) and an IPP.

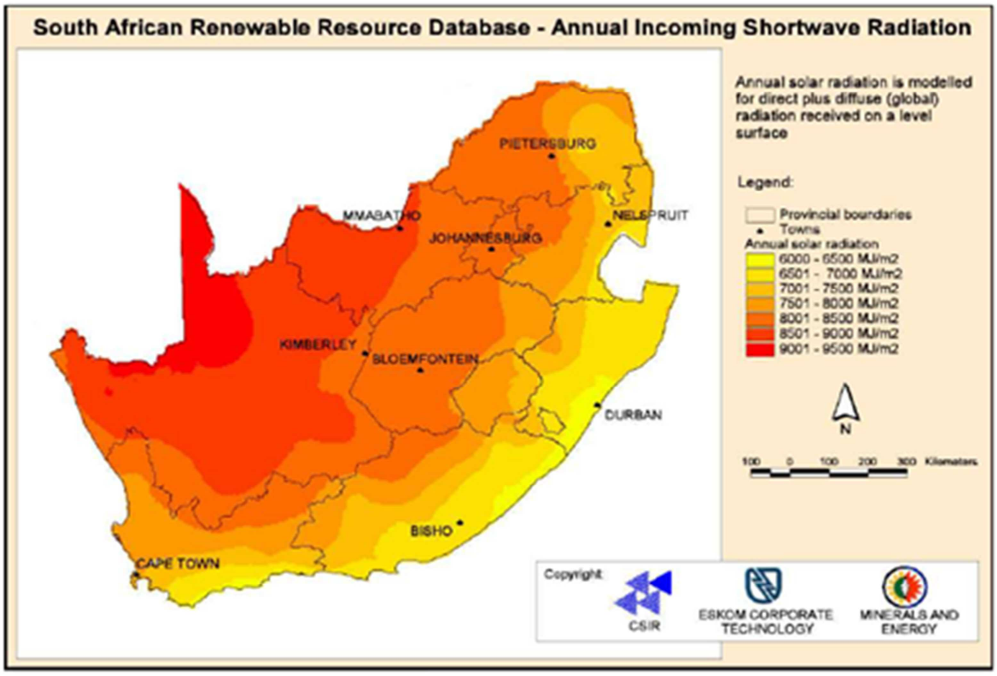

Figure 1. 1: Annual Solar Radiation for South Africa

Source: DME (2003)

The average daily solar radiation in South Africa ranges from 4.5 to 6.5 kWh/m^2 (DME 2003), whereas in the United States solar radiation is about 3.6 kWh/m^2, and for Europe and the United Kingdom solar radiation is about 2.5 kWh/m^2. Two types of solar energy systems exist: photovoltaic[2] (PV) and concentrator photovoltaic (CPV). PV is the conventional form of electricity generation from solar cells, whereas CPV is a relatively new technology where concentrated light is used. The main difference between solar technology and other renewable energy sources has been the large gap in production costs. However, remarkable decreases in solar production costs have narrowed this gap. Owing to technological advances, production costs have been declining by 20 percent for each doubling of production (Stanford Business School, 2004).

Currently, few South African studies have investigated the economic feasibility of the deployment of solar energy infrastructure. This study aims to contribute to this field of study by assessing the economic viability of solar energy provision, specifically CPV solar energy. More specifically, this study performs a private and social cost-benefit analysis (CBA) of the

[2] “Photovoltaic” originates from two words: “photo”, meaning light, and “voltaic” meaning electricity (European Photovoltaic Industry Association (EPIA), 2006).

deployment and maintenance of CPV to a rural Eastern Cape community, namely the Tyefu area, and determines the cost-effectiveness of CPV compared to that of conventional PV.

The private CBA is concerned with the expected efficiency of a CPV system in terms of the revenue earned (the upper limit of the submitted price) by a private investor in relation to its project cost. The social CBA, on the other hand, is concerned with the expected efficiency of a CPV system in terms of the electricity cost savings it offers in relation to its project cost. Both CBAs are thus only concerned with the cost consequences of electricity generation in a micro-economic sense. They do not claim to account for non-electricity-related surpluses realised in other sectors.

1.2 OBJECTIVES OF THE STUDY

The objectives of this study are to:

- Provide a description of the concept of solar power generation, the study area and a CPV project (Chapter One);
- Provide a theoretical overview of the methodology of cost-benefit analysis and cost-effectiveness analysis (Chapter Two);
- Describe the costs and benefits of installing and maintaining a CPV system (Chapter Three);
- Present a case study of a CPV project in the Tyefu area, Eastern Cape, which draws on aspects of the methodology described in Chapter Two (Chapter Four); and
- Provide conclusions and recommendations based on the results of the case study presented in Chapter Four (Chapter Five).

1.3 THE CONCEPT OF SOLAR POWER

Passive solar energy refers to the design of buildings for harnessing the sun's energy, whereas active generation is the capturing of the sun's energy to convert it for other applications. Active solar-based renewable technologies absorb energy from the sun into solar PV panels consisting of cells. Each PV cell consists of two layers of semiconductor material usually composed of silicon crystals. Impurities are intentionally added to the crystallized silicon since alone is not a very good conductor of electricity - this process is known as doping. The bottom layer of the cell is usually doped with boron, which bonds with the silicon to facilitate a positive charge (P). The top layer is doped with phosphorus, which bonds with the silicon to facilitate a negative charge (N). The surface between the resulting ‘P-type’ and ‘N-type’ semiconductor is called the P-N junction. This junction can be clearly seen in Figure 1.2.

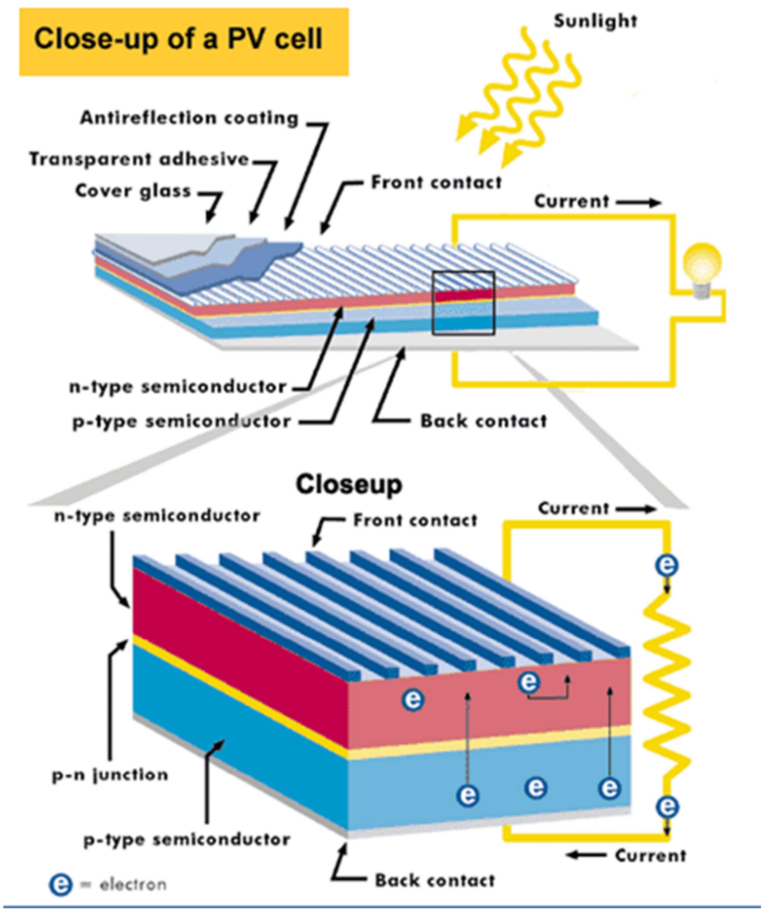

Figure 1.2: Close up of a PV Cell

Source: NJIT (2009)

Electron movement at this junction produces an electric field that only allows electrons to flow from the P-type layer to the N-type layer. Once sunlight enters the cell, its energy knocks electrons loose in both layers. Due to the opposite charges of the layers, the electrons want to flow from P to N. Thin wires run along the top of the N-type layer to provide an external circuit, allowing the electrons to flow, thus producing electricity (New Jersey Institute of Technology (NJIT), 2009). The amount of electricity produced by a PV cell depends directly on the amount of sun light available. Simply, the greater the intensity of light, the greater the flow of electricity generated (EPIA, 2006).

The sunlight entering the cell can be concentrated or non-concentrated. Conventional solar PV systems make use of non-concentrated sunlight, whereas concentrator applications use mirrors or lenses to focus or concentrate sunlight onto photovoltaic material. The concentration of sunlight increases the intensity of the light, which allows the generation of more electricity. The optic elements (such as lenses) multiply the sunlight intensity by factors that range from 2 (low concentration) to more than 1000 (high concentration). Figure 1.3 depicts the principle arrangement of a CPV concentrator.

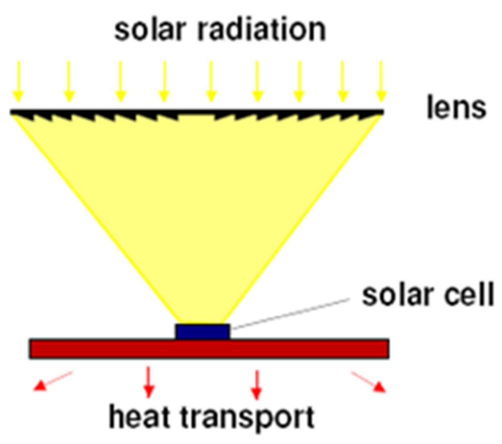

Figure 1.3: Principle Arrangement of a CPV concentrator

Source: PV Technology Research Advisory Council 2007

Sunlight is concentrated by optical devices like lenses or mirrors thereby reducing the area of expensive solar cells, and furthermore increasing their efficiency (PV Technology Research Advisory Council, 2007). The motive for applying this technology is to generate maximum electrical power with the minimum solar cell area which would in turn significantly lower the costs of photovoltaic power generation (Daido, 2011a).

Both conventional PV and CPV systems can be used for grid-connected electricity generation and off-grid (stand-alone) generation, the latter being the most common application, where both photovoltaic technologies gain their advantage (Winkler, 2005). The useful life of a PV cell is a function of manufacturing methods and quality of the material used. Applications based on silicon material are often given a manufacturer’s warranty of 25 years or more, although the expected useful life is much longer. CPV requires that the sun's orbit be tracked by moving the system accordingly, which also allows for a longer exposure time of the cells during the day (PV Technology Research Advisory Council, 2006).

1.4 THE STUDY AREA

For the purposes of this case study, a small, rural settlement in the Eastern Cape province of South Africa was selected. The settlement is called Tyefu and consists of five villages, namely Ndlambe, Ndwayana, Glenmore, Pikoli and Kalikeni (Monde-Gweleta, van Averbeke, Ainslie, Ntshona, Fraser and Belete 1997) and falls under the jurisdiction of the Ngqushwa Local Municipality.

This settlement was selected for four reasons. First, Tyefu is very remote and the majority of households are not connected to the grid (Maliti, 2010). Second, the existing community is very poor and previously disadvantaged. Third, many households in Tyefu are without Eskom generated electricity. Finally, the irradiance levels in this area are ideal for the use of solar systems.

1.4.1 PHYSICAL FEATURES

1.4.1.1 Geographical Location

The study area (33°10'34.46"S 26°54'53.66"E) is shown in Figure 1.4.

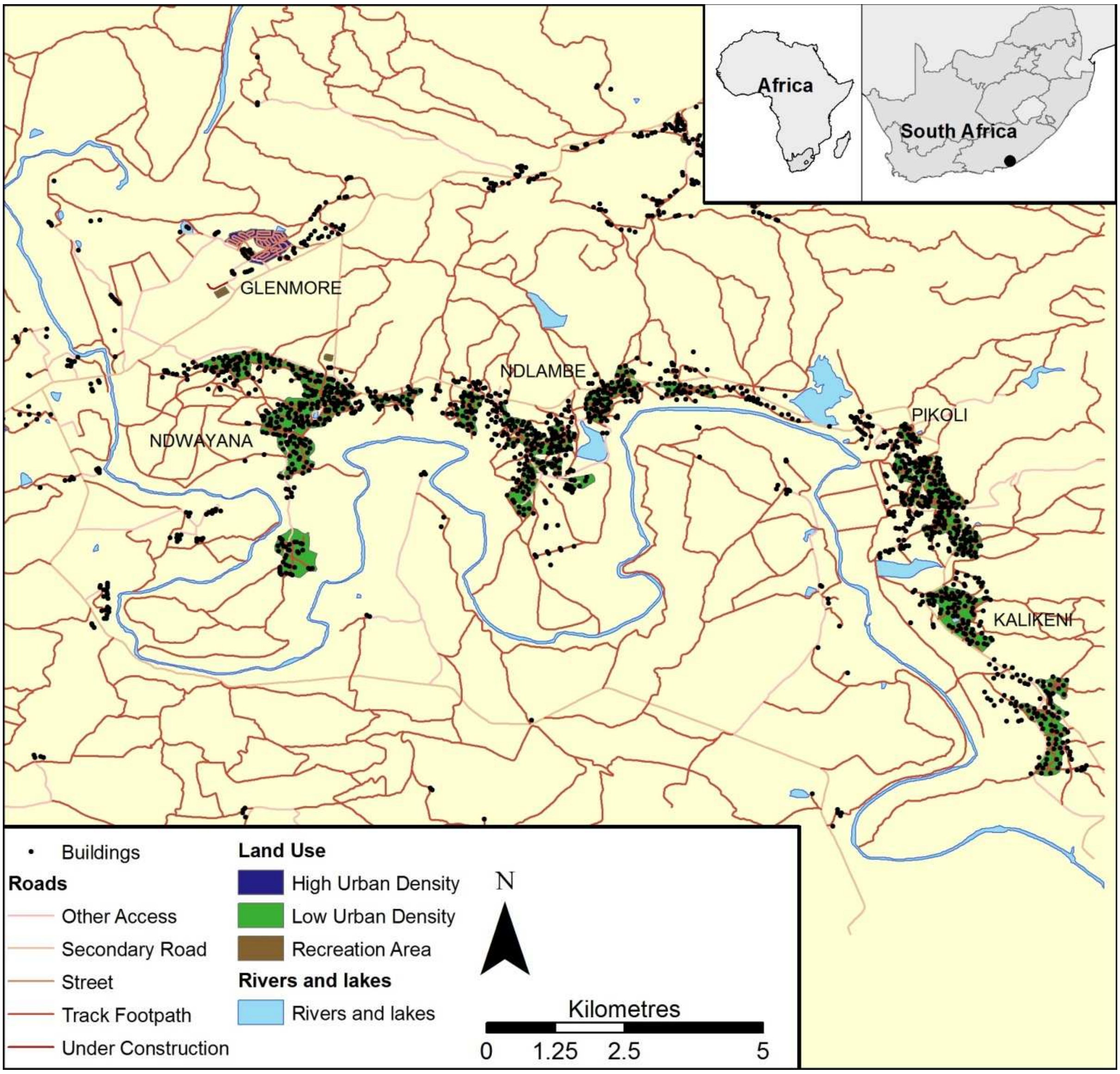

Figure 1.4: Tyefu Irrigation Scheme

Source: Vink (2011)

Tyefu is situated 117m above sea level and is bordered by the Great Fish River. The administrative seat of the Ngqushwa Local Municipality, Peddie, is located approximately 19km east of the settlement.

1.4.1.2 Climate

Table 1.2 shows the average monthly direct normal irradiance (DNI) data for Tyefu.

Table 1.2: DNI Data for Tyefu

Month	DNI ($Wh/m^2/day$)
January	5 911
February	5 233
March	5 005
April	5 119
May	5 219
June	4 852
July	5 331
August	5 152
September	5 166
October	4 555
November	5 198
December	6 553
Annual average	5 274

Source: National Renewable Energy Laboratory (2011)

DNI is the direct radiation per square meter per day reaching a plane facing the sun. This is the type of radiation that is needed for CPV, as the lenses concentrating the light need to be aligned to the sun. Table 1.2 gives DNI data for the study area of approximately 5 000 $Wh/m^2/day$, which is ideal for CPV systems. DNI is adversely affected by overcast and rainy conditions, but the data in the table considers this in its calculation.

1.4.2 SOCIO-ECONOMIC FEATURES

1.4.2.1 Background

Tyefu falls under the Ngqushwa Local Municipality, which in turn falls under the jurisdiction of the Amathole District Municipality, Eastern Cape Province (Ngqushwa Local Municipality, 2011).

Before 1994, Tyefu was part of the Ciskei (a homeland created by the Apartheid government) (Ainslie, 2006). Prior to 1981 (the year in which the Ciskei gained independence from South Africa), the Apartheid government practised 'betterment planning' in the Tyefu area, *inter alia* this entailed placing rural people in demarcated residential areas in order to rehabilitate agricultural land and conserve the environment. The Tyefu community, however, resisted the betterment planning and as a result the villages that make up the community remain scattered to this day (see Figure 1.4) (De Wet, 1989).

1.4.2.2 Land Use

The Tyefu area is well suited to intensive agriculture (Bembridge, 2000). The area was identified as being ideal for the farming of soft citrus and navel oranges, baby carrots, cabbage, potatoes, cauliflower, brussel sprouts, dry beans, durum wheat, cotton and maize (Bembridge, 2000). As a result, the Tyefu irrigation scheme was developed in 1976 to provide irrigation water to approximately 5400 ha on the east and west banks of the Great Fish River (Bembridge, 2000). During 1977 and 1978 respectively, 230 ha was developed at Ndlambe and Pikoli, followed by another 106 ha at Kalikeni in 1981. In 1984 another 137 ha was added, and in 1986 another 171 ha was developed. In total 644 ha was established.

Owing to a number of problems, the scheme has been abandoned. Currently, most Tyefu residents are engaged in subsistence farming. This farming is composed of both cultivation fields and communal grazing for livestock.

1.4.2.3 Employment and Income Levels

The local communities in Tyefu are poor. The majority of households (66.8%) in the region earn less than R1500 per month (Ngqushwa Local Municipality, 2011). Most households depend on pensions and social grants as their main source of income. According to Monde-Gweleta *et al.* (1997), in 1995 state transfers constituted 54.8 percent of the income of plot-holding households. A staggering 78 per cent of residents in the Ngqushwa Local Municipality area are unemployed (Ngqushwa Local Municipality, 2011).

Table 1.3 gives an indication of the employment and income levels in the Eastern Cape as a whole, the Amathole District Municipality, and specifically, the Ngqushwa Local Municipality where Tyefu is located.

Table 1.3: Percentage Unemployment and Households with Monthly Income Less than R1500 for the Amathole District

	Unemployment (%)	**Household Income < R1500/month**
Eastern Cape	53.5	65.2
Amathole	52.7	67.0
Ngqushwa	78.0	66.8

Source: Ngqushwa Local Municipality (2011)

1.4.2.4 Current Energy Sources and Electricity Needs

Traditionally, unelectrified rural, households such as those found in Tyefu have obtained their energy from several sources. These sources include paraffin, candles, liquefied petroleum gas (LPG), dry-cell batteries, car batteries, wood, and diesel and petrol generators. Paraffin is commonly used in rural areas because the distribution infrastructure exists, the fuel can be bought in different quantities, and paraffin appliances are affordable and available in these areas (Aitken, 2007). The most common application for paraffin is cooking. The fuel is also used for heating water (for consumption and washing), lighting, space heating and ironing.

Candles are readily available and can be purchased in varying quantities. Candles are most commonly used for lighting. Alternatives for those households not using candles for lighting, include paraffin, LPG (fairly uncommon) and wood (Aitken, 2007).

Like paraffin, LPG's most widespread use in the Eastern Cape is for cooking. LPG is also used for heating water, ironing, refrigeration, space heating and lighting (Aitken, 2007), but cannot compare with the prolific use of paraffin.

A study by Aitken (2007) showed that the Eastern Cape had the highest level of car battery usage. Dry-cell batteries are mainly used to power TV's, radios, Hi-Fis, tape recorders, clocks and torches (Aitken, 2007). However, car batteries must be recharged and in the Eastern Cape, the average frequency of car battery recharge was every 17 days (Aitken 2007).

Even though other fuel sources are available, wood still prevails as an energy source in rural households. The traditional means of obtaining wood has been to collect it from the surrounding area within the community. However, households are becoming accustomed to purchasing wood. According to (Aitken, 2007), approximately 45 percent of wood-using households in the Eastern Cape purchase some or all of their wood. This can be attributed to decreasing supplies of wood in the areas where wood is gathered. The primary application of wood is for cooking. Other uses are for heating water, ironing and space heating (Aitken, 2007).

The use of diesel and petrol generators is not significant with only 3 percent of the sample households in the Eastern Cape using generators (Aitken, 2007). This can be attributed to the high capital and maintenance costs of the generators. With regards to the usage of generators, households mainly use it for low to medium appliances such as TVs, radios and lighting (Aitken, 2007).

The Ngqushwa Municipality identified 84 households in the Tyefu area as not having electricity. These households formed the sample on which the demand for electricity, and thus the project, is based. The amount of electricity required to replace some of the traditional energy sources is calculated below and was established, by using Aitken’s (2007) study and personal correspondence from Purcell (2011). Figure 1.5 provides the floor plan of a sample household for which a CPV system can provide electricity.

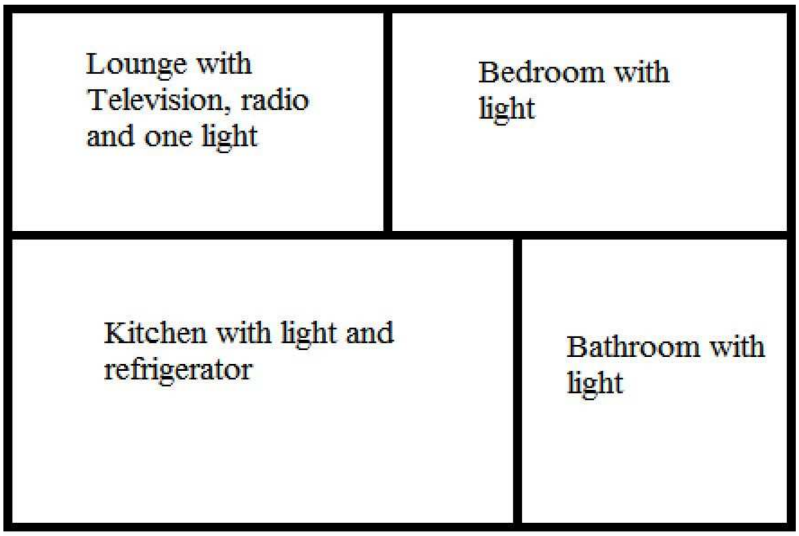

Figure 1.5: Sample Household

The figure depicts a household which uses four fluorescent lamps, a television set, a radio and a refrigerator. In order to provide an equivalent amount of energy to light four rooms, run a television set, radio and a refrigerator for one year, the typical Tyefu household requires:

- 6.39 litres of paraffin (lighting) at a cost of R 639.24 per annum.
- 22 charges for a car battery (TV) at a cost of R333.44 per annum.
- 57 sets (4 batteries per set) of dry cell batteries (radio) at a cost of R902.26 per annum.
- 20.11 kilograms of LPG (fridge) at a cost of R854.77 per annum (Purcell, 2011).

These costs were calculated by using an energy conversion table (see Appendix C), where the cost of useful energy is determined per traditional fuel.

1.5 THE TYEFU CPV ELECTRIFICATION PROJECT

1.5.1 PROJECT DESCRIPTION

The project simply entails the installation and operation of a CPV system with the electricity generating capacity of 30kWp and an annual output of 30.3MWh per annum. The CPV modules used are mounted on a dual-axis system in order to track the sun's movement. A battery bank is used to store the energy produced for use at non-generating hours.

It is clear that Eskom or IPPs could implement the project in other rural areas . This would align well with Eskom's attempts to mitigate grid instability issues, by investing in off-grid, distributed generation, co-generation and small-scale renewable projects (Eskom, 2011). If an IPP were to undertake the project, they would engage in the bidding process to supply the electricity generated by the system.

The major effect of the project is the provision of electricity to a community who did not have it before. The costs of the project will be borne by whoever takes it on.

1.5.2 FEATURES OF THE PROJECT

The project encompasses three components. One component relates to the acquisition and transport of the materials and equipment needed. The second component relates to the installation of materials and equipment. The final component relates to the operation and maintenance of the installed materials and equipment.

If the project were to be undertaken by Eskom, it would also be managed by them. On the other hand, if IPPs were to undertake the project, they would outsource management to a services engineering and managing company.

The choice of manufacturer of the CPV system would be dependent on those undertaking the project. There are several large manufacturers of CPV systems, namely, Solfocus, Amonix, Arima, Emcore, Soitech (Concentrix) and Skyline Solar.

Installation could be carried out by a services engineering and management company regardless of whether Eskom or an IPP were to undertake the project. In addition, installation of the 30kWp system would take approximately 2 months[3].

Maintenance of the system could also be performed by a services engineering and management company. Basic maintenance can be performed by trained locals. However, more advanced technical maintenance would have to be undertaken by more highly trained individuals within the management company.

1.6 PRINCIPAL SOURCES OF INFORMATION

Table 1.4 gives the primary and secondary sources consulted during the study.

Table 1.4: Principle Sources of Information Used in this Study

1. Primary Sources	1.1 Centre for Energy Research NMMU - Personal communication (Prof EE van Dyk)
	1.2 Ngqushwa Local Municipality - Personal communication (Mr P Skade)
	1.3 ASGISA Eastern Cape - Personal communication (Mr D Maliti)
	1.4 Energy & Development Group - Personal communication (Mr C Purcell)
	1.5 Valldoreix Greenpower - Personal communication (Mr R Pardell)
	1.6 Reclam - Personal communication (Mr J Goosen)
	1.7 DB Shenker - Personal communication (Ms J Emery)
2.Secondary Sources	2.1 Journals
	2.2 Textbooks
	2.3 The Internet

[3] 10 out of 12 months remain in year zero for the running of the CPV plant. The benefits and costs in year zero are thus 10/12 of the original values (see Appendices A and B).

1.7 ORGANISATION OF THE DISSERTATION

An overview is provided of the methodology of CBA and CEA in Chapter Two. Chapter Three describes the costs and benefits of installing, operating and maintaining a CPV system. The methodology described in Chapter Two is applied to a CPV project in Chapter Four, and final conclusions drawn and recommendations made in Chapter Five.

CHAPTER TWO: A THEORETICAL OVERVIEW OF THE METHODOLOGY OF PROJECT ANALYSIS

2.1 INTRODUCTION

Three types of decision-making tools can be applied in project analysis, namely an economic impact assessment (EIA), a cost-benefit analysis (CBA) and a cost-effectiveness analysis (CEA). In an EIA, all conceivable economic variables that might be affected by the execution of a project are considered in order to show the total economic effects of a reallocation of resources. It is broader in scope than a CBA. Further discussion of an EIA falls beyond the scope of this study.

A CBA is a technique used to assess the relative desirability of alternative projects. Under this methodology the equivalent money value of the benefits and costs to society are compared using decision-making criteria to assess whether a project is desirable (Watkins, 2010).

CBA is not a perfect decision making tool, however, it does provide decision makers with a transparent and impartial apparatus to use when implementing a prospective project.

Nonetheless, this strength can be nullified by corruption on the part of politicians and other influential people involved with the project or policy in question. These parties may skew results of the CBA in order to favour their own interests, thus going against the very essence of a CBA's rationale of being an instrument to allocate resources equally among society.

Although the strength of CBA is that it increases efficiency through the better allocation of scarce resources, it can also be criticised from a theoretical viewpoint. CBA rests on the Kaldor-Hicks criterion, where the winners compensate the losers of a project. However, such compensation is usually not provided by information contained in the CBA.

A CEA is a technique used for choosing the least-cost alternative among competing projects, when resources are limited (American College of Physicians (ACP), 2000). It is a form of analysis that compares the relative costs and outcomes of two or more courses of action. It is often used when prohibitive difficulties are encountered in placing monetary values on the benefits of a project. A CEA is appropriate if it has already been determined that a certain project of a certain size is worth undertaking, and the only concern is to execute the project as inexpensively as possible.

A significant problem in CEA is the absence of enough effectiveness data (ACP, 2000). It is common that the analysis runs ahead before hard data becomes available. Subjective estimates of experts are usually employed (ACP, 2000).

Cost data can also be of concern. The source of cost data will influence the outcome of a CEA. Cost data can either be modelled or measured in practice (ACP, 2000). If data is modelled assumptions are usually made, whereas real-life data incorporates unanticipated costs (ACP, 2000). Both a CBA and a CEA are employed in this study.

In this chapter, the following topics are covered: the welfare basis for CBA, the basic steps in the application of CBA methodology, the implementation issues faced by the CBA practitioner, the CBA methodology used in the case study, the basic steps in the application of a CEA, and the CEA methodology used in the case study. A short summary concludes this chapter.

2.2 THE WELFARE BASIS FOR CBA

The fundamental reasoning behind CBA is based in welfare economics. Welfare economics is a field of economics that focuses on the optimal allocation of resources and how this allocation affects the well-being of society (Investopedia, 2010). In other words, it considers the total good that is achieved at a current state in time as well as how it is distributed and how it affects the common good of society (Investopedia, 2010).

The most popular economics criterion, the Pareto criterion, defines welfare improvements as actions where no one can be made better off without simultaneously making at least one other person worse off (Economicae, 2008). The most important feature of this criterion is that it enables policy-makers to determine conclusive welfare changes. However, some believe that in practice, it is almost impossible to take any social action, such as a change in economic policy, without making at least one person worse off (Stavins, 2004). As a result, the Kaldor-Hicks criterion is often applied since it is less restrictive than the Paretian approach. The Kaldor-Hicks criterion refers to a “potential” Pareto improvement instead of a Pareto improvement. That is, a change is welfare-improving if the winners from the change could (in principle) fully compensate the losers, with at least one winner still being better off (Stavins, 2004). Most CBAs are in fact based on this criterion (Stavins, 2004).

2.3 APPLICATION OF CBA

Hanley and Spash (1993) distinguish eight essential steps in conducting a CBA: defining the project, identifying impacts, asking which impacts are economically relevant, physically quantifying impacts, performing a monetary valuation, discounting, applying decision criteria and sensitivity analysis. These steps are briefly discussed below.

(a) Defining the Project. The first step of a CBA is defining the scope of the project. More specifically, the reallocation of resources being proposed and the population of winners and losers must be defined (Hanley and Spash, 1993). This step is taken to set the boundaries of the analysis, and to keep the analysis more focused. The population of winners and losers are defined as the people or community who are affected by a proposed project. The definition of the population, or study area, is often specified by the organization sponsoring the analysis (Watkins, 2010).

(b) Identification of Project Impacts. The second step is to identify all impacts (costs and benefits) that arise due to the implementation of the project. In this regard, Hanley and Spash (1993) draw attention to two important concepts, namely ‘additionality’ and ‘displacement’. Additionality refers to the net effects of the project, whereas, displacement refers to the “crowding out” effect of the project on other similar projects. Additionality is related to the “with or without” aspect of CBA. More specifically, the impact of a project is the difference between what the situation would be with and without the project (Fuguitt and Wilcox, 1999). The alternative to the project must be explicitly specified and taken into account in the evaluation of the project. The researcher must be aware that the with-and-without comparison is not the same as a before-and-after comparison (Watkins, 2010).

(c) Specifying Economically Relevant Impacts. Once the analyst has identified all the project impacts, he/she must identify all the resource impacts that have good or bad consequences for social welfare. This may require specialized knowledge, such as specific scientific knowledge in a field that the analyst is not familiar with (Fuguitt and Wilcox, 1999). Positive impacts (benefits) can either be increases in the quantity or quality of goods that generate positive utility or a decrease in the price at which they are supplied. Negative impacts (costs) will be the opposite (Hanley and Spash, 1993).

(d) Physical Quantification of Relevant Impacts. This step involves establishing the physical amounts of the cost and benefit flows for the project, and identifying when they will occur in time (Hanley and Spash, 1993). When physically quantifying the costs and benefits the analyst must once again refer to the 'with or without' principle (these costs and benefits occur incrementally, that is, they arise with the project, compared to without it). The analyst must specify what would happen if the project was not pursued, this is known as the baseline scenario. Following this, changes from the baseline scenario, resulting from the implementation of the project, must be identified. Good changes are benefits[4], and bad changes are costs[5] (Fuguitt and Wilcox, 1999).

(e) Monetary Valuation of Relevant Effects. The costs and benefits are valued in monetary units in order for them to be co-measurable (Hanley and Spash, 1993). This is needed in order to reach a conclusion as to the desirability of the proposed project (Watkins, 2010). Money is used as a common unit of measurement purely because of convenience. Markets generate the relative values of all traded goods and services, as relative prices. These relative prices carry valuable information for the researcher (Hanley and Spash, 1993). During this stage, the researcher must predict prices for value flows extending into the future. Knowledge of prices extending over the lifespan of the project is crucial for the estimation of the project benefits. The researcher must take note that prices may change over time in both real and nominal terms. Economic analyses are usually realised using real or constant values, in other words, by measuring benefits and costs in units of stable purchasing power (Whitehouse, 1992).

[4] Incremental benefits= (Benefits with the project) - (Benefits without the project)
[5] Incremental costs= (Costs with the project) - (Costs without the project)

(f) Discounting of Cost and Benefit Flows. In addition to the costs and benefits being measured in equivalent money values, they must also be measured at a particular point in time (Watkins, 2010). Specifically, amounts must be converted into present value (PV) terms. This is due to the time value of money (money today is more valuable than money in the future) (Hanley and Spash, 1993). The PV of a cost or benefit (X) received in time (t) is calculated as follows:

$$PV(X_t) = X_t[(1+i)^{-t}] \ldots\ldots\ldots\ldots (2.1)$$

where i is the discount rate. The term in the square brackets is known as the discount factor. The higher the value of t is, the further away in time is the cost or benefit, and thus the lower the discount factor. Furthermore, the higher the discount rate i, for a given t, the lower the discount factor. This is because a higher discount rate means a greater time preference for things now rather than later (Hanley and Spash, 1993).

(g) Generating Decision Criteria. One or more of the following three decision-making criteria are used to aid decision-making in CBA, namely, the net present value (NPV), the internal rate of return (IRR) and the discounted benefit cost ratio (BCR). NPV is a selection measure that asks whether the sum of discounted benefits (B) exceeds the sum of discounted costs (C). The NPV can be formally expressed as follows:

$$NPV = \sum_{t=o}^{n} B_t(1+i)^{-t} - \sum_{t=o}^{n} C_t(1+i)^{-t} \ldots\ldots\ldots\ldots (2.2)$$

The criterion for a project's acceptance is if it generates a positive NPV. The IRR is the rate of interest, i, that will produce a NPV of zero (if this interest rate is used as the discount rate). More formally:

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} = 0 \quad \text{(2.3)}$$

The IRR decision rule is that the project should proceed if the IRR exceeds the discount rate (i). The BCR is a different way of expressing the NPV. More formally, the BCR can be expressed as follows:

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \quad \text{(2.4)}$$

If the BCR exceeds unity, then the project may proceed (Hanley and Spash, 1993). An additional decision-making criterion is also used in CBA, namely the payback period. This decision-making criterion determines the number of years it takes to recover the initial investment (Hirschey, 2003). The payback period calculation may use either discounted net benefits or actual net benefits. The latter suffers from not taking the time value of money into account (Hirschey, 2003). The payback period can be expressed as follows:

$$Payback\ period = Number\ of\ years\ to\ recover\ investment \quad \text{(2.5)}$$

A project is more desirable, the shorter the payback period. Taking all the above-mentioned decision-making criteria into account, the decision maker has to decide on whether a prospective project is desirable or not. However, the different decision-making criteria can give conflicting results, which may result in acceptance of an undesirable project. Since the NPV, IRR and the BCR share a common focus on the present value of costs and benefits, they therefore have a high degree of consistency in terms of the decision to accept or reject a project (Hirschey, 2003). The project payback period criterion should be used as a complement to the other criteria, since this measure does not always employ the time value of money and it does not evaluate the ultimate impact the project may have on society or a firm (Hirschey, 2003). However, if more than one project is being considered the NPV, IRR and the BCR criteria can give conflicting results in terms of ranking the projects from most to least desirable (Hirschey, 2003).

The NPV measures the relative appeal of competing projects by the discounted difference between costs and benefits. The NPV is considered an absolute measure of desirability of a project. Contrarily, the BCR measures the ratio of costs and benefits of a project and is a relative measure of the desirability of a project. Therefore, in terms of ranking projects, the NPV favours large projects, whereas, the BCR ranks the project with the highest benefit per cost, regardless of project size.

Comparing the IRR and NPV, the two decision-making criteria will lead to identical decisions when there are conventional costs and benefits (negative flow in first year and positive flows for the remainder of the project) over the project's life (University of Pittsburgh, 2011). However, when the benefit cost profile differs significantly, the NPV and IRR can give conflicting results when the discount rate is changed. The IRR and NPV can also lead to identical results when there is project independence; where the decision to accept or reject a project does not affect the decision to accept or reject another project (University of Pittsburgh, 2011). Using the IRR is thus preferred when only one project is being considered.

Changes in the discount rate can result in changes in terms of project rankings (Hirschey, 2003). The reversal of project rankings takes place at a discount rate called the 'crossover discount rate'. This is where the NPV for two or more competing projects is equal. However, this is not a common occurrence and the crossover discount rate is often too high or low to affect project rankings (Hirschey, 2003). When the crossover discount rate does become relevant, it can be calculated as the IRR of the cash flow difference between two project options (Hirschey, 2003). Upon the calculation of the crossover rate, the decision maker has to decide whether to have confidence in the NPV or IRR in resolving the ranking reversal problem. Most often the NPV is chosen, since it results in the value maximisation of a project (Hirschey, 2003). The NPV is also favoured over the IRR since the NPV assumes that interim cash flows are re-invested at the cost of capital whereas the IRR assumes re-investment at the IRR, which is not realistic (Hirschey, 2003). The IRR is also expressed in percentage form, which can be misleading. For example a 20 percent IRR on R1 000 000, is preferred to a 40 percent IRR on R100 000.

In deciding between using the NPV or the BCR in terms of ranking, the decision maker would have to assess the available resources. If resources are plentiful the NPV would be preferred, if resources are limited the BCR is preferred in allocating scarce resources (Hirschey, 2003).

(h) Sensitivity Analysis. The last stage of a CBA is conducting a sensitivity analysis. In all *ex ante* cases, the analyst must make predictions concerning future physical flows and future relative values (Hanley and Spash, 1993). This introduces uncertainty in the study and is the reason why sensitivity analyses are conducted. A sensitivity analysis entails altering one or more parameters of the CBA and then recalculating the decision-making criteria in order to check how these variations affect the CBA outcomes (Health and Safety Executive (HSE), 2010). The following key parameters are usually changed:

- The discount rate;
- Physical quantities and qualities of inputs;
- Shadow prices of these inputs;
- Physical quantities and qualities of outputs;
- Shadow prices of these outputs; and
- Project life span (Hanley and Spash, 1993).

2.4 IMPLEMENTATION ISSUES

CBA is not a perfect analytical tool that provides a definite solution to all project-related questions. The sections below examine several of the most pertinent practical issues encountered in applying CBA. The following topics are covered: the valuation of costs and benefits, the selection of the social discount rate, the treatment of risk and uncertainty, the incorporation of distributional factors, and the time horizon of the project.

2.4.1 THE VALUATION OF COSTS AND BENEFITS

2.4.1.1 Valuation at Market Prices

Market prices reflect social values only under conditions of perfect competition; which is rarely the case for developing countries (Kashem, 2010). In a perfectly competitive market the equilibrium price of a product is equivalent to both the marginal social cost (MSC) of its production and its marginal social benefit (MSB) to consumers. In a market that is operating in this manner it would be acceptable to use the market price to value the costs and benefits of a project. However, this is seldom the case. The reasons why the market price is sometimes not equivalent to the MSC and MSB are explored below.

(a) Imperfect Competition in Commodities Markets. Imperfect competition is a market situation where firms have a measure of control over commodity's price and the quantity produced. This market structure normally arises when one firm, or a relatively small number of firms, supplies an industry's output (Paris, 2010). The profit-maximizing firm in an imperfectly competitive market will produce at a level of output where marginal cost equals marginal revenue but the market price charged will be higher than the marginal cost (Hanley and Spash, 1993). Figure 2.1 charts this situation for a monopolist.

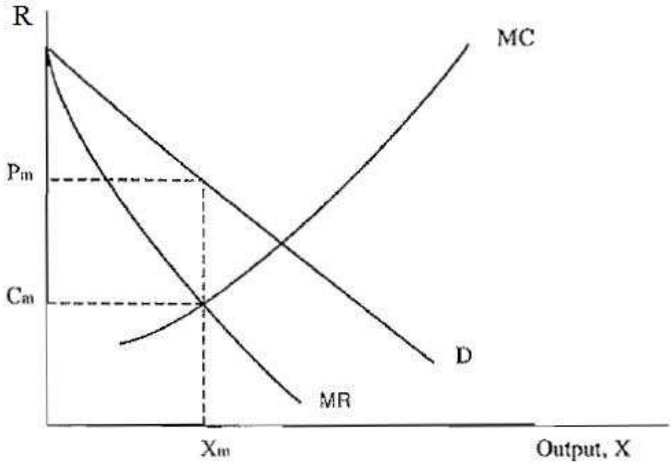

Figure 2.1: Price and Marginal Cost for a Monopolist

Source: Adapted from Hanley and Spash (1993)

The marginal cost is represented by curve MC, the demand by curve D, and the marginal revenue is described by curve MR. The monopolist maximises profits by producing at X_m and charging a price P_m. This price is higher than the true cost to the economy, C_m (Hanley and Spash, 1993). Therefore, the market price must be adjusted downwards to reflect the true cost (MSC) to the economy.

(b) Imperfect Competition in Factor Markets. In a perfectly competitive factor market producers will purchase resources at the point where marginal revenue product equals the value of marginal product, which in turn is the price of the input. In an imperfect factor market, producers purchase until the input price equals the marginal revenue product. However, this input price is less than the value of the marginal product. Owing to this, it is required that the input price be adjusted upwardly (University of Victoria, 2011).

(c) Unemployment. Usually when an unemployed resource is used in a public project the opportunity cost of employing it is equal to zero, except in the case of labour (Rosen, 2001). The opportunity cost in terms of labour is foregone leisure time (Nicholson, 2004). With respect to capital the opportunity cost of lost production is zero (assuming that no depreciation applies) (Nicholson, 2004). If depreciation is related to usage, then the future use of the capital is reduced.

The difference between labour and capital, is the conservation of productive capacity. Labour cannot transfer unused effort to the future, whereas with capital, productive capacity can be transferred (Nicholson, 2004).

(d) Taxation and Subsidisation. Indirect taxes or subsidies are often incorporated into market prices and therefore these prices do not reflect the MSC of production. In private analysis, commodities are valued inclusive of taxes and subsidies, whereas in social CBA, commodities are valued net of indirect taxes and subsidies to correct for these distortions.

(e) Externalities. Externalities represent a failure in market price systems to reflect the full picture of the relationships between firms or between firms and people (Nicholson, 2004). In the absence of externalities, the costs a firm incurs accurately measure social costs. In other words, the prices of the resources the firm uses represents all the opportunity costs involved in production. However, when a firm creates externalities, there are additional costs, such as those that arise from external damage. An example of external damage is that of pollution created from the burning of fossil fuels, such as coal. In burning this coal, firms respond only to the input cost of the coal, and do not take the social costs of its pollution into account. Externalities can also have a positive impact (Centre of Excellence (COE), 2000).

All external effects are caused by the following aspects: interdependency, lack of property rights, and high transaction costs. Interdependency refers to the fact that one person’s activity affects the utility or production of another. However, the market system fails to ‘price’ this interdependence. Thus, an affected party is uncompensated. The lack of, or weak, property rights means the affected party is unable to demand or ask for compensation. Lastly, the cost of negotiation, implementation and enforcement between the parties may be high (COE, 2000).

Externalities can be classified as either pecuniary or technological (Nicholson, 2004). A pecuniary externality is an externality that is brought about through prices rather than through real resource effects. For example, an influx of city-dwellers buying second homes in a rural area can drive up house prices, making it difficult for young people in the area to acquire property in the market (Nicholson, 2004). In contrast, technological or real externalities have a direct resource effect on a third party. Pollution created by private firms, which affects surrounding communities adversely, is an example of this type of externality. Pecuniary externalities should not be taken into account in CBA, whereas technological ones should (Nicholson, 2004).

The concept of property rights is one method of dealing with externalities. Property rights are the legal specification of who owns a good and the types of trade that the current owner is permitted to undertake. Some goods may be defined as common property that is owned by society, and may be used by anyone. Some goods may be defined as private property that is owned by specific people. If the only cause of an externality is the absence of property rights, the problem may be resolved through bargaining (if bargaining is costless) irrespective of who owns the rights. This is known as the Coase Theorem (Nicholson, 2004). However, the costs of bargaining are never zero in the real world. Therefore, the Coase Theorem cannot always be relied on.

A second solution to externalities, is that of implementing an excise tax equal to the external cost. The tax causes the firm to reduce its output to the socially optimal amount (Nicholson, 2004). This type of tax is commonly known as a Pigouvian tax; a tax that brings about an equality of private and social marginal costs (Nicholson, 2004).

(f) Public Goods. Another failure of the price system to yield an efficient allocation of resources is due to the existence of goods that can be provided to users at zero marginal cost and on a nonexclusive basis to everyone. Examples of this type of good are national defence, provision of justice and national roads (Nicholson, 2004).

The free-rider problem is a feature of public goods, where a consumer of the goods does not pay for it in the hope that other consumers will. All people have the incentive to be free riders since they know they will benefit from the goods regardless of whether or not they contribute to production. The free-rider problem, therefore, hinders the formation of market prices (Nicholson, 2004).

The above discussion from (a) to (f), gives reasons why market prices will rarely equal the marginal social cost of production and marginal social values to consumers. Owing to this, shadow pricing is often prescribed as an alternative method of valuing costs and benefits.

2.4.1.2 Valuation at Shadow Prices

When market prices are either absent or are inadequate in reflecting the opportunity cost of the resources involved in a project, shadow pricing is employed (Commonwealth of Australia, 2006). Shadow prices are the social opportunity costs of the resources used (and correspondingly for outputs generated by the project) (Layard and Glaister, 1994). These prices reflect the marginal change in the availability of commodities (output) or factors of production (input).

(a) Adjustment for Taxes and Subsidies. If a project's inputs are redirected from other users, the price these users would have been willing to pay is the opportunity cost of the inputs (the price gross of taxes and net of subsidies) (Commonwealth of Australia, 2006). However, if the input demand is the result of increased production, the opportunity cost of the resource is the best alternative use (the price net of taxes and gross of subsidies) (Commonwealth of Australia, 2006).

(b) Adjustment for Traded Goods. Project inputs can either be purchased locally or purchased abroad. These goods are known as 'traded goods', the shadow price applied depends on the source of the goods. In terms of traded goods, ‘border prices’ are used as shadow prices (Sheth, 2010). With respect to imports, this is the CIF (cost-insurance-freight)[6] price, and for exports, this is the FOB (free-on-board)[7] price (Organisation for Economic Co-operation and Development (OECD), 2010). Border prices must also include domestic margins (transport and distribution costs) (Jongeneel, 2011).

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[6] The CIF price is the cost of an import plus insurance and freight expenses to the port of destination.
[7] The FOB price is the price of an export at the port of origin before insurance and freight charges are added.

Having established the border price, it is then converted by means of an exchange rate to internal price levels (Mullins, Mosaka, Green, Downing and Mapekula, 2007). In the absence of free currency markets, the value of the exchange rate does not, however, reflect the scarcity value of a currency (Mullins *et al.,* 2007). Interventions in the currency market, such as the pegging of a currency or the restrictions on capital flows are examples of intervention (Mullins *et al*., 2007).

The two principle approaches in resolving the issue of exchange rates are the United Nations Industrial Development Organization (UNIDO) and the I.M.D. Little and J.A. Mirrlees (LM) approaches (Sheth, 2010). The UNIDO approach measures shadow prices in terms of domestic price. In order to reach the domestic price, international prices are multiplied with a shadow exchange rate[8]. The LM approach, like the UNIDO approach, also subscribes to the use of shadow prices in order to correct for market distortions (Sheth, 2010). However, the LM approach measures shadow prices in terms of international prices (Mishra, 2006). In other words, the border price is not measured in terms of domestic currency, but rather with the foreign exchange rate.

(c) Adjustment for Non-Traded Goods. With respect to non-traded inputs, the UNIDO approach subscribes them to be broken down into the resources required to produce them, and each sub-component is then valued at border prices in order to calculate the true costs. The residual non-traded components of the inputs are valued at the domestic willingness to pay (WTP) criterion[9] and any labour is measured at the shadow wage rate (Sheth, 2010).

For non-tradables the LM approach subscribes the use of detailed input-output tables in order to account for all non-traded inputs that go into their production (Sheth, 2010). If detailed input-output tables are not available, a conversion factor (the ratio of domestic to international prices) can be used for approximation of shadow prices for non-traded goods (Sheth, 2010).

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[8] The ratio of domestic to international prices.

[9] The willingness to pay criterion values inputs at the price the marginal individual is willing to pay for them (Commonwealth of Australia, 2006).

2.4.1.3 Non-Market Valuation Approaches

In the absence of market prices, non-market valuation techniques can be used to value costs and benefits.

These techniques can be broadly categorised as revealed preference techniques (indirect methods) and, stated preference techniques (direct methods) (Ganderton, 2010). The former involves drawing inferences from observing human behaviour or choices made by individuals. These methods are based on the assumption that the non-marketed good or service affects the preferences expressed by consumers about other marketed goods or services (Markandya, 2010). The latter involves finding a WTP measure in circumstances where markets fail to reveal this information.

The most commonly used revealed preference approaches include the hedonic pricing method (HPM) and the travel cost method (TCM), whereas the most often applied stated preference approaches include the contingent valuation method (CVM) and the choice modelling approach (CM). These approaches are discussed below.

(A) Revealed Preference Techniques

1) Hedonic Pricing Method:

Background. The HPM is based on Lancaster's (1966) characteristics theory of value. According to this theory an individual's utility depends on the characteristics of the good consumed (Lancaster, 1966). The HPM recognises environmental service flows as elements of a vector of variables describing a good on the market (Hanley and Spash, 1993). The method breaks the item down into its constituent characteristics, and acquires estimates of the contributory value of each characteristic.

The most common application of HPM is in the housing market. Analysts use this valuation approach to value environmental goods (bads), such as noise pollution and water quality, with respect to the market price of houses. Another application of the HPM is estimating the value of avoiding the risk of death or injury by examining the price differentials between wages in risky versus non-risky jobs (Gundimeda, 2011).

Application. Hedonic prices are calculated through comparing similar goods that differ with regards to the quality of one characteristic. The basic premise behind the method is to utilise the variation in the price of a good (often housing) that is the result of a variation in a characteristic (often an environmental characteristic) of the good. The analyst does this in order to evaluate the WTP for the characteristic in question (Markandya, 2006).

In applying HPM two assumptions are made. Firstly, the whole area under study is considered a single housing market. Individuals are assumed to have all information about alternatives and are free to choose any location in the area (Batalhone, Batalhone and Mueller, 2002). Secondly, the housing market is assumed to be near or at equilibrium. This means that all individuals should maximise their utilities in choosing a house, given alternative prices due to location (Batalhone *et al.*, 2002).

The analysis is conducted in two stages. In the first stage, multiple regression analysis is employed to estimate the Hedonic Pricing (HP) function (Gundimeda, 2011). This function relates the selling price of properties in a housing market to the characteristics of the houses and can be expressed as follows:

$$P_n = f(s_1, s_2, s_3, \dots, s_i; n_1, n_2, n_3, \dots, n_j; e_1, e_2, e_3, \dots, e_k) \dots\dots\dots\dots \quad (2.6)$$

Where s is indicative of structural vectors, n is neighbourhood vectors, and e is environmental vectors. Structural characteristics relate to the structure of the house, such as the number of rooms. Neighbourhood characteristics relate to variables such as the class of the area. The environmental characteristics are items such as air quality, noise pollution, and proximity to recreational areas (Gundimeda, 2011).

Freeman (1993) states that equation 2.6 may be linear or non-linear. If it is linear, then the implicit prices are constants.

To find the implicit price of an environmental characteristic, for example, one would partially differentiate the hedonic function with respect to the characteristic in question ($\frac{\partial P_h}{\partial e_1}$). According to Hanley and Spash (1993), the implicit price, ($\frac{\partial P_h}{\partial e_1}$), is known as the rent differential, r, and is a measure of the value of a marginal change in the quantity of the environmental good, e_1. The rent differential represents the marginal cost of purchasing an increase in the environmental variable, e_1, and the marginal benefit of a one unit increase in the variable (if the market is operating perfectly) (Hanley and Spash, 1993).

The second stage of HPM is the derivation of the demand curve for the environmental good, using the implicit prices obtained from the previous stage (Rosen, 2001). During this stage implicit prices, r, derived from stage one are regressed against e_1 and different socio-economic characteristics of the household to obtain a marginal WTP for the environmental good (Gundimeda, 2011). The estimation of a demand curve for e_1 is reliant on assumptions about the supply side of the market (Hanley and Spash, 1993). A short run situation is commonly suggested where supply is fixed for houses.

As with any demand curve, the relationship between price and quantity is portrayed. The derived demand curves show how much a household is willing to pay for an environmental good. The area under the demand curve, for a given quantity of e, indicates the welfare benefit to the household (Gundimeda, 2011).

The HPM is not a perfect methodology and has faced some criticism, however, it is still useful in its application and is utilised in economic analyses. These weaknesses, together with its strengths are now discussed below.

Weaknesses

(1) Omitted Variable Bias. During estimation of the HP equation the analyst must choose which variables to include. If an important variable is left out of the equation it can cause problems with the reliability of the estimation. With respect to the example of house prices, if a characteristic is left out which effects house prices significantly, and which is correlated with some of the included variables, this will lead to biased estimates[10] of coefficients and the implicit prices (Hanley and Spash, 1993).

Another cause of omitted variable bias is the exclusion of expectations of environmental quality. Current levels of environmental quality are normally used in the HPM. Future concerns for the environment can, however, have an influence on current house prices and thus the implicit prices of characteristics in the equation.

(2) Multi-Collinearity. If there is some correlation between variables in the hedonic pricing equation, multi-collinearity[11] is present (Hanley and Spash, 1993). If the correlation is strong enough it can significantly affect the estimation of the coefficients of the variables (Studenmund, 2010).

(3) Market Segmentation. Housing markets are not homogeneous but are rather heterogeneous (segmented) in nature and differ with regards to locational, structural or neighbourhood attributes. If this segmentation is not taken into account, the coefficients will become biased in the HP function (Leong, 2011). Ideally, separate hedonic price functions should be calculated for each segment (Hanley and Spash, 1993).

For separate HP functions to exist two conditions need to be met. Firstly, purchasers must not participate in multiple markets. Some barrier to mobility of buyers needs to exist. Barriers include lack of information or a desire for ethnically homogeneous neighbourhoods. Secondly, the structure of demand or supply or both, needs to be different across markets.

The existence of market segmentation does not make the HPM a futile method, but rather complicates its application. It is conceptually possible to estimate HP functions for each sub-market (Freeman, 1993).

(4) Restrictive Assumptions. Several restrictive assumptions are made when applying the HPM. These assumptions are explained below.

[10] This bias is called omitted variable bias or specification bias (Studenmund, 2010).
[11] This is most often imperfect multi-collinearity. Perfect multi-collinearity is a condition where one explanatory variable explains all the variation in the dependent variable (Studenmund, 2010).

In order to interpret the marginal implicit prices as households' WTP, requires that a state of equilibrium be present to the given vector of housing prices and that this vector of prices just clears the market for the given stock of houses and attributes (Freeman, 1993). To satisfy the equilibrium assumption more assumptions are needed. Households require perfect information in order for equilibrium to be achieved. Transaction costs and moving costs are assumed to be zero, and the price vector is required to adjust instantaneously to changes in demand and supply (Freeman, 1993).

Owing to market imperfections in the property market, market equilibrium is not possible. Prices do not adjust automatically and instantaneously to changes in demand and supply (Leong, 2011).

The model assumes that both buyers and sellers have perfect information regarding the housing product. Both buyers and sellers spend substantial time in gaining as much knowledge as possible regarding the product due to large amounts of money been spent on it, but in reality perfect information may never be fully realised (Leong, 2011). Transaction and moving costs are also present in the real world and will keep the market out of equilibrium.

(5) Perceptions. A criticism often lodged against the HPM is that households do not perceive differences in air quality. Freeman (1993) hypothesised that air pollution enters the utility function negatively. Statistical procedures can reject this hypothesis if no correlation is found. This criticism is, however, not directed at the underlying theoretical model but is directed at the valuation of air pollution specifically (Freeman, 1993).

(6) Identification Problem. The identification problem occurs during the second stage of the HPM. The procedure relies on the assumption that enough information exists regarding the various variables that affect prices. Biases occur, however, when insufficient market data that does not identify all significant variables are present (Roessler and McDaniels, 1994).

(7) Data Intensive. The HPM is a very data intensive method. It requires large numbers of observations for prices and attributes in order to estimate the HP function (Gundimeda, 2011).

Strengths

(1) Market Efficiency. When there is a change in demand or supply factors, property markets are relatively efficient in responding to these changes. A change in this information for both buyers and sellers in the market is taken into account, thus the property market can be a good indicator of value (King, Mazzotta and Markowitz, 2000a).

(2) Based on Actual Choices. One of the predominant strengths of HPM is that actual market data are used to estimate non-market values. The application of observed market behaviour removes any doubt between the intentions and actions of consumers. HPM is therefore less prone to the systematic biases that may influence hypothetical valuation measures (Roessler and McDaniels, 1994).

(3) Market Data. Property sales data and property characteristics are promptly available through many sources (such as real estate services and municipal services) and can be related to other secondary data sources to obtain descriptive variables for the analysis (King *et al*., 2000a).

(4) Environmental Application. HPM is specifically designed to evaluate environmental qualities and attributes. It is possible to use the method to infer demand for non-marketed commodities from markets with related commodities (Roessler and McDaniels, 1994).

2) Travel Cost Method:

Background. The first proposal of the TCM was by Hotelling (1931), and was further improved by Clawson (1959) and Clawson and Knetsch (1966). The TCM's economic rationale is provided by neoclassical economic theory of demand modelling (Du Preez and Hosking, 2010). The economic premise of the TCM is that the time and travel cost expenses that visitors incur to visit a site represents the “price” to access the site. WTP can be calculated based on the number of trips that visitors make at different travel costs. This is similar to the estimation of WTP for a marketed good given the quantity demanded at different prices.

The TCM is mostly applied to valuing recreational sites, such as parks, lakes and similar public areas, which host recreational activities and are located a fair distance away from many people, which requires users to travel to the site (Karasin, 2011).

TCMs can be subdivided into single-site and multiple-site models. The former includes the zonal (Clawson-Knetsch) and the individual methods, while the latter includes the random utility model (RUM). The three types of TCMs, mentioned above, are discussed below.

The Zonal TCM. The zonal TCM (also known as the Clawson-Knetsch method) is a relatively easy process to carry out since the data requirement is small. Secondary data is mainly applied (Du Preez and Hosking, 2010).

The zonal TCM involves seven steps in its application. Firstly, the zones of origin surrounding the recreation site are defined (usually done by specifying concentric zones of varying size around the recreational site (Roessler and McDaniels, 1994)). Data is then obtained for the number of visitors per zone and for the amount of visits per zone made in the last year (Hanley and Spash, 1993). This data is then converted into a visit rate, by dividing the total visits per year by the zone's population (expressed in thousands). Hereafter, the average travel distance per zone to the site is calculated and multiplied by the mean cost per kilometre. This results in an estimate of the travel cost per trip (Fix and Loomis, 1997). A time cost pertaining to travel may also be added to the travel cost estimate. A trip generating function (TGF) is estimated which relates visits per person to travel costs. A demand curve is drawn by increasing the admissions fee[12] and taking note of the related visits from each zone for each fee increase (Hanley and Spash, 1993). Lastly, the area beneath the demand curve is calculated. This area provides an estimate of the total value of the recreation site per year.

[12] Admissions fees are used in TCM as a proxy of actual price.

The Individual TCM. In order to undertake an individual TCM analysis, a TGF is estimated using survey data (Bockstael, 1995). Included in the TGF are additional explanatory variables, such as, income, age, gender, educational attainment, substitute sites and recreation site quality (Du Preez and Hosking, 2010). An example of such a TGF is specified below:

$$V_{ij} = f\left(TC_{ij}, TT_{ij}, SE_{ij}, E_{ij}\right); i = 1 \dots n \dots\dots\dots\dots\dots\dots (2.7)$$

where, V_{ij} is the number of trips taken to the site per annum, TC_{ij} is the travel cost in order to visit site j, TT_{ij} is the round trip travel time, SE_{ij} are socio-economic characteristics of the respondent, S_{ij} is information on substitute sites, E_{ij} is a characteristic for information on environmental quality and n is the number of visitors (Du Preez and Hosking, 2010).

Following the estimation of a TGF is the estimation of the demand function. The area under the demand curve is used to estimate the consumer surplus from the recreational activity (Bockstael 1995; Hanley and Spash, 1993). Alternatively, it is possible to use the estimated coefficients of the travel cost (TC_{ij}) covariate for count data models to calculate the consumer surplus. The average consumer surplus per visit is calculated as the negative inverse of the travel cost coefficient $(\frac{-1}{B_{TC}})$ (Du Preez and Hosking, 2010). In order to calculate the total consumer surplus, the average number of visits is multiplied by the consumer surplus per visit, multiplied by the number of visitors.

The Random Utility Model of Site Choice. This model considers an individual's discrete choice of one recreation site from a set of several possible sites (Parsons, 2001). As substitute sites are included in the choice sets of the RUM, the multi-collinearity problem that commonly affects single-site individual TCMs is prevented.

The RUM shows how an individual i chooses from a set of discrete choices each representing a vector of characteristics (Parsons, 2001). The utility derived from a visit to a beach j, for example, is explained by the indirect utility function,

$$V_{ij} = V(z_{ij}, x_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

where, z_{ij} is a vector of attributes of beach j, including travel and time costs to the beach; and x_i is a vector of individual i 's characteristics. If the utility from visiting beach j exceeds the utility of all other beaches, k in the choice set, where $= (1,2, \ldots, j, \ldots, n)$, individual i will visit beach j. The utility is assumed to be a function of a systematic or observable (observable to both the researcher and the decision maker) element (V_{ij}) and a random error (ε_{ij}) (unobservable to the researcher, but known to the decision maker),

$$U_{ij} = V(z_{ij}, x_i) + \varepsilon_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

The conditional logit (CL) is a mathematical representation of the RUM that is commonly employed. For the CL it is assumed that the ε_{ij} is independent and has a type I extreme value distribution. The probability, $Pr_i(j)$, that individual i chooses beach j out of k beaches is given by,

$$Pr_i(j) = \frac{\exp(V_{ij})}{\sum_{j=1}^{k} \exp(V_{ij})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

where, $\exp(.)$ = the antilog function.

However, a common problem with the CL is the axiom of independence from irrelevant alternatives (IIA) (Haab and McConnell, 2003). This property states that relative probabilities of choosing between any two alternatives are unaffected by the introduction or removal of other alternatives (Haab and McConnell, 2003). If the estimation of the CL results in a violation of the IIA principle, then the nested logit (NL) can be applied. The NL allows the estimation of a series of decisions by means of the development of a decision tree (Haab and McConnell, 2003).

The strengths along with the weaknesses of the three TCMs are briefly discussed below.

Weaknesses

(1) Choice of Dependent Variable. With regards to the zonal TCM and the individual TCM, no consensus exists regarding the choice of the dependent variable. Two options exist, namely visits from a given zone, or visits by an individual (Hanley and Spash, 1993).

The second option is carried out by collecting data on visits per annum for each respondent (VPA). The first option is conveyed as visits per capita (V/Pop). Consumer surplus estimates for a given site show great variances according to which option is used (Hanley and Spash, 1993).

(2) Multi- Purpose Trips. Two types of respondents are encountered in travel cost studies: visitors for whom the visit to the site "is on the way" or part of the purpose of their travels, and visitors for whom the visit to the site is the only reason for their travels (Hanley and Spash, 1993).

For the former only a portion of their travel costs should be apportioned to the site being valued. One way of solving this problem is for researchers to ask these visitors to score the importance of their visit to the site in relation to the enjoyment of the entire journey. An alternative would be to exclude these respondents from the analysis and compute a separate consumer surplus figure for them (Hanley and Spash, 1993).

(3) Holiday Makers and Residents. Some visitors to the site in question could be travelling from their temporary holiday accommodation in close proximity to the site of interest. Only their travel costs from their permanent residence should be allocated to the valuation of the site (Hanley and Spash, 1993).

(4) Calculation of Distance Costs. Once data is gathered on distances travelled by respondents to the site, distance costs must be calculated. This depends on whether respondents used public transport or their own transport to arrive at the site. For respondents with their own transport the following two options can be used: A price must be set per kilometre, either using petrol costs (to estimate the marginal cost), or the "full costs of motoring" (this includes wear and tear, insurance etc.) (Hanley and Spash, 1993). Transport cost is used for those respondents who used public transport. Consumer surplus estimations will differ significantly depending on respondents mode of transport.

(5) Calculation of Time. The determination of time is controversial. Time is a scarce resource and therefore has an implicit price. Most people travelling are doing so whilst off work. Travel cost time may be calculated as the foregone wage rate. Travel time costs in the range between 25 percent and 50 percent of the wage rate are commonly employed (Bateman 1993; Bowker, English and Donovan 1996; Zawacki, Marsinko and Bowker, 2000). The basis that the opportunity cost of time may be calculated as the wage rate can be questioned. Since most recreational time is spent at the cost of other recreational activities, the opportunity cost of visiting a particular recreational site is the forgone opportunity to visit other recreational sites (Hanley and Spash, 1993). For this reason, some studies decide to omit travel time costs completely (Hanley and Spash, 1993).

(6) Substitute Sites. Substitute sites are only taken into account in the RUM of TCM. The zonal and individual TCMs ignore substitutes (Koundouri, 2008).

(7) RUM Values Characteristics. The RUM takes explicit account of substitute sites. However, it only allows for valuation of each attribute of a recreational site visit, and does not value entire sites (Campbell and Brown, 2003).

(8) RUM Assumes Constant Number of Trips. The main problem with the RUM is that it does not explain the number of trips taken. This entails that when the quality of a site changes, only the estimate of per trip benefit changes. The number of trips made is assumed to be constant (Campbell and Brown, 2003).

(9) Problems of Using OLS in Individual TCMs. Trip data are the dependent variable in the TCM demand function. It is measured in terms of the number of trips for a time interval (season or year). The TGF results from a data generating process[13] based on an unknown probability distribution function, characterised by non-negative integers. In addition to the problem of non-negative integers, the estimation of a TGF in TCM requires a separate modelling technique to deal with the problem of the data having a truncated nature (truncated at zero trips, since no data is collected on visitors taking no trips).

Taking the problems of zero truncated and non-negative integers into account, estimation of the TGF by the OLS method would result in biased estimators (Creel and Loomis, 1990). The regression slopes estimated by OLS would be biased toward zero, when the dependent variable is truncated (Maddala, 1983).

In order to resolve this issue alternative models should be used. Poisson and negative binomial count data models have been employed (Creel and Loomis, 1990). The standard Poisson distribution is represented by:

$$f(W = w) = \frac{\exp(-\lambda)\lambda^{w}}{w!} \qquad (2.11)$$

Equation 2.11 is a discrete density function, where w is an element of the set of non-negative integers, λ is known as the population rate parameter. The Poisson random variable W has expectation $E(W) = \lambda$, and variance $Var(W) = \lambda$. The equality of the mean and variance is not realistic, owing to the conditional variance often being greater than the mean. This results in an over-dispersion problem.

[13] Generally known as a count data process (Creel and Loomis, 1990).

Another model that deals with the problem of over-dispersion and relaxes the mean-variance equality is based on the negative binomial probability distribution. The unobserved heterogeneity that is not captured by the Poisson model is represented in the negative binomial model (Du Preez and Hosking, 2011). This is done by the addition of an extra parameter, α. A likelihood ratio test, based on the parameter α, can be administered, in order to test for no over-dispersion (Du Preez and Hosking, 2011).

Strengths

(1) Consistency with Theory. Estimates are generally consistent with consumer demand theory which states that quantity demanded is negatively related to price (Ward and Beal, 2000).

(2) Price and Income Elasticities. The differences in elasticities for different sites is what one would perceive to be true prior to using the TCM. The method displays this intuition: sites with more substitutes display demand that is more price sensitive than those with less options (Ward and Beal, 2000).

(3) Available Data. The main strength of TCM is that the secondary data required is readily available (Roessler and McDaniels, 1994). Recreational sites usually record such data, such as visitor addresses.

(4) Avoids Hypothetical Pitfalls. Since TCM uses actual consumer expenditures in order to calculate non-market values it avoids biases created by other valuation techniques that employ hypothetical scenarios (Roessler and McDaniels, 1994).

(B) Stated Preference Techniques

1) Contingent Valuation Method:

Background. The use of CVM was initially suggested by Ciriancy-Wantrup (1947), who applied the methodology to soil erosion. Ciriancy-Wantrup (1947) opines that the prevention of soil erosion creates "extra market benefits" that can be valued through the elicitation of people's WTP. However, Davis (1963) was the first to empirically employ the CVM. He estimated the benefits of goose hunting via surveys.

CVM has gained widespread acceptance as a versatile approach for benefit estimation (Venkatachalam, 2004). It is a survey-based methodology, where an appropriately designed questionnaire describes a hypothetical market for a good, where none exists. People are then asked to express their maximum WTP for a hypothetical change in the level of provision of the good (Pearce, Pearce and Palmer, 2002). It is called "contingent" valuation, since people are asked to state their WTP, contingent on a specific hypothetical scenario and description of the environmental service. The CVM could also ask respondents their willingness to accept (WTA) compensation for a change in the level of environmental service flows (Hanley and Spash, 1993). WTA is an approach that asks the respondent how much he/she is willing to accept for the loss of the environmental good (public good) or service. The WTP approach is applied where respondents do not have rights to the good in questions and must purchase it, whereas WTA approach is applicable where respondents have property rights to the good in question, and the right to alter current conditions must be bought from them (Breedlove, 1999). Owing to concern that respondents would give unrealistically high answers for WTA questions, almost all previous CVM studies ask respondents their WTP instead (Arrow, Solow, Portney, Leamer, Radner and Schuman, 1993). CVM can be used to estimate both "use"[14] and "non-use"[15] values for environmental goods and services, and it is the most widely used method for estimating non-use values (King, Mazzotta and Markowitz, 2000b).

[14] "Use" values are losses experienced by those who, in different ways, actively use the environmental resources in question (Arrow *et al*., 1993).

[15] "Non-use" values are when people do not actively make use of the resource in question, but derive satisfaction from the mere existence of the resource (even if they intend to never make use of it) (Arrow *et al*., 1993).

The application of CVM is usually carried out in six steps (Hanley and Spash, 1993).

Application. The first step of the CVM is to set up the hypothetical market (the reason for payment). The context of the hypothetical scenario must be as realistic as possible so that realistic responses can be obtained. The manner in which the respondent is hypothetically expected to pay for the good is also described and, this is known as the “bid-vehicle” (Arrow *et al*., 1993). The bid-vehicle, for example, could be a form of tax, entry fee or trust fund payment. Respondents react adversely towards taxes although this is a realistic form of payment. A bid vehicle using voluntary contributions may induce free-riding behaviour and lower bids than usual. Thus the WTP question forms the crux of the CVM questionnaire. It is important that the questionnaire be tested before the main survey. This is usually carried out by initial interviews and/or focus groups (King *et al*., 2000b).

The next step involves administering the survey. The survey may be executed in several ways, such as by mail, telephone or personal interviews. Personal interviews are the most often applied method as they offer the most scope for detailed questions and answers (Hanley and Spash, 1993). However, personal interviews are the most expensive survey type. Mail surveys have the advantage of being less expensive than personal interviews, they have the ability to reach large populations in less time, and they avoid interviewer bias. The disadvantage, however, with mail surveys is the very low response rate. Telephonic interviews have the disadvantage of being time consuming, but are relatively inexpensive to undertake (King *et al*., 2000b).

In the survey, respondents are asked what their WTP/WTA is. These figures are derived in several ways known as elicitation techniques. There are four main types of elicitation techniques, namely, bidding games, the payment card approach, open-ended questions, and closed-ended questions.

The bidding game approach randomly assigns a particular bid from a range of predetermined bids. The bid may either be a high or low bid, and the respondent is then asked to answer yes or no to that particular bid. This process is continued until the highest positive response is recorded (Venkatachalam, 2004). The advantage of this technique is that it gives better results since it imitates a market situation where respondents have the opportunity to research their preferences (Venkatachalam, 2004). However, this approach requires the presence of interviewers (which increase costs of research) and may suffer from starting point bias[16].

The second approach is the payment card approach. A payment card is presented that indicates a range of WTP values for a public good. The respondent must choose his/her maximum WTP value (Venkatachalam, 2004). The advantage of this method is that it avoids starting point bias, by allowing the respondent to pick the starting bid (Wattage, 2001). However, the payment card approach is liable to biases relating to the range of numbers used on the card. It can also not be used via telephone interviews (Arrow *et al*., 1993).

The third technique is the open-ended elicitation technique. The researcher asks the respondent what their maximum WTP for the public good is (Venkatachalam, 2004). Open-ended elicitation is free from starting point bias, but suffers from large non-response or protest bids (Arrow *et al*., 1993).

The closed-ended approach[17] is preferred to the open-ended technique since it allows the respondent to make easier choices, and corresponds to actual purchase decisions individuals face in the real world. The respondent is shown a value and must answer yes or no to indicate their willingness to pay the value given (Arrow *et al*., 1993). A further variation of the closed-ended approach (single bounded DC) is the double-bounded DC, where the respondent is asked a follow up question to say yes or no to a higher or lower bid (Arrow *et al*., 1993). While closed-ended questions help respondents in making a decision, it has significantly higher values than open-ended questions (Arrow *et al.*, 1993).

The third step involves computing an average WTP/WTA bid. This is done once all responses have been collected. Firstly, the analyst must differentiate between valid and invalid responses. Protest bids are an example of invalid bids, where the respondent refuses to answer a valuation question (Hanley and Spash, 1993). Refusal to answer a question could be due to mitigating circumstances, such as not being able to pay for the public good in question, or due to opposition to a procedural aspect of the contingent valuation itself (Jorgensen, Syme, Bishop and Nancarrow, 1999). A protest bid could also be the result of one feeling that their vote will have no significant effect on the outcome of the project (Arrow *et al*., 1993). A decision must be made on how to identify and treat these outliers (Hanley and Spash, 1993).

[16] A bias where the starting bid in the bidding game influences the final value of the WTP.

[17] Also known as the single question method, the single-bounded dichotomous choice (DC) approach or the take-it-or-leave-it approach (Venkatachalam, 2004).

By employing statistical methods to estimate the mean, that are less sensitive to extreme observations, and by taking into account other measures of value besides the population mean, analysts are able to detect and eliminate outliers and protest bids (McFadden, 1994).

However, these alternative approaches have their own drawbacks. If observations are to be pre-screened for suspicious responses, the identification criteria chosen are debatable. Pre-screening raises the issue of classification errors, which can cause post statistical analysis to be inconsistent (McFadden, 1994). Alternative measures can also be used, instead of the population mean. Alternatives, such as medians and trimmed means,[18] may be used. Nevertheless, these estimators may also be biased, when the distribution is skewed (McFadden, 1994).

The fourth step entails estimating a bid function (Hanley and Spash, 1993). The rationale of these functions is to test the statistical viability of responses (Hanley and Spash, 1993). Characteristics of respondents are related to WTP in order to generate the bid function. WTP values are used as the dependent variable and are regressed on several explanatory variables. Four estimation models are usually employed: OLS, Tobit, Logit and Probit models (Hosking, 2010). These models can be classified into two groupings. Firstly, the OLS and Tobit models explain WTP variation in monetary terms (Hosking, 2010). These are continuous dependent variable models. Secondly, the Logit and Probit models explain the probabilities of WTP. These are binary response dependent variable models (Hosking, 2010).

Stage five involves aggregating data. The sample chosen must represent the target population. This includes all individuals whose utility has the probability of being influenced significantly by the project (Hanley and Spash, 1993). Moving from the sample mean to the population mean, the average bids are multiplied by the sample population in order to reach the total WTP value (Hanley and Spash, 1993). It is important here that the sample mean has no bias, as it will be reflected in the total WTP value. The time period and discount rate used during aggregation is also of importance as this has a significant influence on the total WTP value (Hanley and Spash, 1993).

The last stage involves critically analysing the results of the CVM. An important part of this step is the identification of biases that might have occurred during the CVM process.

[18] Also known as "truncated means". This mean measure is computed similarly to ordinary means, except a specified percentage of extreme observations are omitted from the analysis.

Before these biases of CVM are discussed, guidelines for conducting a CVM, as set out by Arrow *et al.* (1993) in their report on CVM for the National Oceanic and Atmospheric Administration (NOAA) panel, are listed below.

CVM Guidelines

1. Sample type and size: Probability sampling is vital for a survey used in CVM. It can be difficult choosing a sample's specific design and size, and may require the assistance of a professional sampling statistician;

2. Minimise non-responses: Non-responses or protest bids, need to be limited as this may lead to unreliable survey results;

3. Personal interview: Arrow *et al*. (1993) found that personal interviews elicited the most reliable estimates of value. Mail surveys were found to be unreliable. Telephonic interviews have a cost and a centralised supervision advantage. However, personal interviews are the most favoured form of administration;

4. Pre-testing for interviewer effects: During personal interviews, interviewers may add to "social desirability" bias[19]. CVM studies should include experiments that evaluate interviewer effects;

5. Reporting: The following should always be made clear in a CVM report: definition of the population, sampling frame used, the sample size, the sample non-response rate (and its components), and item non-response on all important questions. The questionnaire and all communication with respondents must also be included in the report. Data used in the CVM study should be archived properly in order to be available to interested individuals;

6. Careful pre-testing of a CVM questionnaire: Owing to technical information contained in CVM surveys, it is critical that careful pre-testing be carried out on surveys before eliciting answers from respondents;

[19] This bias occurs when respondents are unwilling or unable to report accurate answers on sensitive topics to defend their reputation (Fisher, 1993).

7. Conservative design: When responses are uncertain, the option that underestimates the WTP should be chosen. A prudent approach increases the reliability of the estimate, as outliers are eliminated;

8. Elicitation format: The WTP format should be used instead of the WTA, since the WTP estimates are generally lower and are thus more prudent;

9. Referendum format: Arrow *et al*. (1993) propose the use of a dichotomous question that asks respondents to vote on a referendum;

10. Accurate description of the programme or policy: The survey needs to be designed in such a manner that enough information is given to respondents about the program or policy being assessed;

11. Pretesting of photographs: The dramatic nature of a photograph may create bias in the CVM. Photographs must be subject to careful assessment prior to being presented to respondents;

12. Reminder of undamaged substitute commodities: A reminder must be given to respondents of substitute commodities (such as other comparable natural resources or the future state of the same resource). This must be done prior to the main valuation question;

13. Adequate time lapse from the accident: In the case of an environmental accident, the survey must be conducted with sufficient time from the accident so that respondents believe that the scenario of restoration is possible;

14. Temporal averaging: By averaging across independently drawn samples (drawn at different time periods), time dependent measurement noise is reduced;

15. “No-answer” option: Included in the main referendum question should be an explicit option for “no-answer” with the “yes” or “no” options. An explanation should also be given by the respondent if he/she chooses the “no-answer” option;

16. Yes/no follow-ups: An open ended question should follow the yes/no response. These answers must also be carefully coded to show the type of response;

17. Cross-tabulation: It is recommended that the survey includes additional questions. Examples of such questions include, among others; income, prior knowledge of site, prior interest in site, attitudes toward big business, attitude towards the environment, distance to

the site, and understanding of the task (Arrow *et al.*, 1993). These questions assist in interpreting the responses to the primary valuation question. The CVM report should also include summaries of WTP broken down by these additional questions; and

18. Checks on understanding and acceptance: The above-mentioned guidelines, as stated by Arrow *et al*. (1993), must be met without creating a survey that is over complicated. Complexity can create low interest levels in respondents.

Biases

(1) Strategic Bias. Two forms of this bias exist, namely free-riding, and over pledging. Free-riding is the result of an individual who understates their true WTP for a public good on the expectation that others would pay enough for the good in question. Over pledging, however, is when an individual thinks that their WTP value will influence the provision of the good in question (Venkatachalam, 2004). The respondent takes the question very seriously and sees that giving a large response is a costless way to make a point (Arrow *et al*., 1993).

(2) Design Bias. Design bias can arise due to payment vehicle bias, starting point bias and information bias. The former is the choice of the payment (bid) vehicle, such as an entrance fee or higher taxes, which can affect the stated WTP. Respondents do not always understand the scenario as intended by the analyst, due to the gap of plausibility and understandability. It is advised that the payment vehicle chosen be neutral (Du Preez, 2002).

Design bias can also result from starting point bias. Starting point bias arises in the bidding game format of elicitation. Respondents may understand the starting point in a bidding game as conveying an approximated value of the good. The payment card overcomes this type of bias (Du Preez, 2002).

WTP values may also change depending on the information given, resulting in a bias known as information bias. An overload effect can occur resulting in the respondent overlooking important information (Jakobsson and Dragun, 1996).

(3) Mental Account Bias. Mental account bias is based on the premise that respondents focus on groups of commodities when making allocative decisions (Jakobsson and Dragun, 1996). A question on endangered species, for example, can result in a response that is the respondent's 'mental account' for all environmental goods (Jakobsson and Dragun, 1996).

A second type of mental account bias exists. This is when respondents allocate an irrational proportion of their disposable income to one scenario (Edwards-Jones, Davies and Hussain, 2000). Arrow *et al*. (1993) suggest that respondents be reminded of the real economic constraints within which their spending decisions are made.

(4) Hypothetical Bias. Hypothetical bias is the divergence between stated payments, in response to a hypothetical opportunity to pay, and actual payments when the opportunity to pay arises in reality. Hypothetical bias occurs as individuals are attempting to make a prediction of their WTP in a hypothetical scenario. The general approach to resolving the problem of hypothetical bias is to close the gap of reality between the hypothetical situation and the payment vehicle (Arrow *et al*., 1993). This solution is easier to implement for studies eliciting use values. Use values are closely related to market situations, for example, paying for a fishing license is more familiar to a respondent than being asked to pay an increased tax for species conservation (Jakobsson and Dragun, 1996).

(5) Non-Response Bias and Sample Selection Bias. In any CVM survey, not all respondents will respond to a questionnaire or an interview request, which creates the possibility of non-response bias or sample selection bias (Edwards-Jones *et al*., 2000). The latter bias occurs when respondents who have a high value for the commodity being valued are more likely to respond than non-respondents. The former bias occurs if the non-respondents and respondents differ in terms of the observable characteristics that affect WTP.

The administration of the survey can result in non-response bias. Mail surveys (particularly those designed to value off-site[20] public goods) that are based on samples of the general population are prone to low response rates. Conducting mail surveys of a more homogenous sample, for example, fishermen or hunters, can increase the response rate. Telephonic and

[20] Individuals may place value on a resource even if no physical contact is made with it. Off-site value is also termed "vicarious consumption" (Dosi, 2000).

personal interviews tend to have a higher response rate, but still experience non-response bias.

The treatment of non-responses could entail several approaches. Some researchers treat all non-responses as zero value, or generalise from the sample directly to the whole population. Alternatively, using weighted least squares, sample values can be adjusted to take into account differences between the sample population and the general population (Jakobsson and Dragun, 1996).

(6) Sequencing. Another problem with the measurement of WTP is the sequencing effect, also known as "question-order bias". This effect happens if a WTP value for a good differs owing to the order of the good in a sequence (Venkatachalam, 2004). This effect takes place in multi-good valuation studies. Sequencing is said to occur due to improper administration of the survey. To minimise this bias the researcher can inform the respondents about what is going to come before asking the WTP questions, and to give the respondents a chance to revise their bids after asking the questions (Venkatachalam, 2004).

Other issues

(1) Difference between WTP and WTA. One of the issues influencing the validity of CVM is the disparity between the WTP and WTA measures. Several reasons for this discrepancy have been given: the income effect, the substitution effect, psychological reasons and transaction costs (Venkatachalam, 2004).

In economics the income effect refers to the effect of extra income on the quantity of a good purchased. WTP is constricted by income, while the WTA is not. The WTP and the WTA for a particular commodity will diverge, if that commodity has a high income elasticity of demand.

The substitution effect also explains the divergence between WTP and WTA. The divergence could range from zero to infinity depending on the degree of substitution (with the presence of positive income elasticity).

Psychological effects also play a role in the divergence between WTP and WTA. Kahneman (1979) developed the "prospect theory", which explains the WTP/WTA discrepancy. The theory proposes that the loss of a commodity for a person is greater than the gain obtained from buying it. Thaler (1980) explained the WTP/WTA divergence with the "endowment effect". This is a hypothesis that people value a commodity more once they have established property rights.

Transaction costs may also play a role in the WTP/WTA disparity. Consumers calculate the total cost of buying and selling a good during a transaction. The total cost will compose of the price of the good and the transaction cost. Taking this into consideration while buying the good, the person's WTP would exclude the transaction cost, whereas, selling the same good, the WTA compensation would include it. Nevertheless, public goods have a weak market, thus the transaction cost theory may not stand (Venkatachalam, 2004).

(2) Embedding Effect. The embedding effect[21] is a situation in which a wide range of variation occurs in the WTP value for the same good, depending on whether the good is valued independently or as part of other goods in a basket. An example of the embedding effect, is when a respondent is asked to give their WTP to preserve eagles, and is then asked in a separate survey their WTP to preserve ten different bird species, and the two WTP values do not differ significantly. One interpretation for this, is the "warm-glow" effect, where respondents give fixed sums, as this gives a feeling of having done something praiseworthy (Arrow *et al.*, 1993). Since embedding affects the validity of CVM studies, Arrow *et al.* (1993) suggest that an internal consistency test be used to assess the validity of results.

Strengths

(1) Flexible Method. CVM is a very flexible method in that it can be used to estimate the economic value of numerous environmental goods. However, it is best suited to estimate

[21] This effect is also known as the scope effect, part-whole bias, disaggregation bias or sub-additivity (Venkatachalam, 2004).

values for commodities that are easy for respondents to understand and conceptualise (King *et al*., 2000b).

(2) Total Economic Value. CVM is an accepted method to estimate total economic value, that is, both use and non-use values (King *et al*., 2000b).

(3) Simple Method. The method requires great attention towards the design and administration of the survey in order to achieve defendable results. However, CVM results are not difficult to analyse and describe in comparison to other valuation techniques (King *et al.,* 2000b).

(4) Corresponds to Theory. The WTP and WTA responses elicited from respondents correspond to theoretically correct (Hicksian) monetary measures of changes in utility (Centre for Marine Biodiversity and Conservation (CMBC), 2011).

(5) Advantages of Conducting CVM in Developing Countries. Respondents in developing countries are open to listening and consider the questions put to them. Response rates are usually very high, and the survey costs for developing countries are usually lower than normal (this allows for larger sample sizes) (CMBC, 2011).

2) Choice Modelling:

Choice Modelling (CM), also referred to as conjoint analysis, is based on random utility theory and on the Lancastrian notion that any good may be defined in terms of its attributes (Brent, 2009; King, Mazzotta and Markowitz, 2000c). These attributes are used as the basis to elicit consumers' value of the good; where a change in the attributes of the good bring about proportionate changes in consumer valuation (Brent, 2009). CM involves the administration of a questionnaire to a sample of respondents, who express their preferences for alternative future resource management strategies called choice sets. Each choice set gives the respondent the result of a number of different strategies. These options are described by a common set of attributes or characteristics. The options are differentiated by each option taking on different levels with respect to the attributes. One of the options is called the “business as usual” (BAU) option, and retains its value in all the choice sets. An experimental design is used to distribute the levels of the attributes in each option that differs from the BAU option. This is done so that respondents face an array of future outcomes (Bennett, 2010). The choices of the respondents of their preferred alternatives demonstrate their willingness to trade-off one attribute against another. The choices implicitly reveal the respondent's marginal value for the components (Brent, 2009). A monetary attribute must exist when describing the options. This makes it possible to measure respondent’s WTP for additional units of the environmental benefits described by the other characteristics (Bennett, 2010).

An example of using CM is the description of a forest in terms of its species diversity, age structure and recreational facilities. Changing attribute levels will essentially result in a different “good” being produced, and it is on the value of such changes in attributes that CM focuses (Pearce and Ozdemiroglu, 2002).

The four types of CMs used in practice are described below in terms of their application. The four types are choice experiments, contingent ranking, contingent rating and pair-wise comparisons.

Types of Choice Models

(a) Choice Experiments. Choice experiments resulted from the fields of transport and marketing. They were used to research trade-offs between the attributes of transport projects and private goods, respectively. Recently, choice experiments have entered the areas of environmental and health economics. Some of the reasons for their increased use is that choice experiments avoid the potential biases of CVM, and more information is gained from respondents (Wilkström, 2003).

Choice experiments are quantitative in nature and are used to measure the relative importance of the different product characteristics that affect consumer choice behaviour (Lagarde and Blaauw, 2009). Respondents are requested to make choices between hypothetically alternative goods. These goods are defined by various attributes. The analyst must research which attributes to include in the limited set. Different combinations of attributes are formulated (these combinations are referred to as “scenarios”). A limited number of attributes are chosen for each scenario using experimental design techniques. These techniques ensure that scenarios are chosen that optimise data obtained from respondents (Lagarde and Blaauw, 2009).

Hereafter, the chosen scenarios are arranged into a series of choice sets. These choice sets are presented to the respondent who must select a scenario from the sets presented. During this stage, the respondent's preferences are elicited (Lagarde and Blaauw, 2009).

The last stage is to run regression techniques in order to model the respondent's choices as a function of the scenario attributes. Once regression has taken place, the analyst can use the coefficients to infer the relative importance of the attributes (Lagarde and Blaauw, 2009).

(b) Contingent Ranking. Contingent ranking proceeds in the same way as choice experiments. However, respondents are asked to rank scenarios in terms of desirability (Bloom, 2010). After this, the rank is regressed against the variables representing the attributes of the good in question (Cuccia, 2008). One disadvantage of this choice model is that it does not correspond to typical market behaviour (King *et al*., 2000c).

(c) Contingent Rating. Contingent rating asks respondents to use a scale (say 1 to 10) to rate each alternative (Bloom, 2010). This choice model also suffers from not displaying common market behaviour (King *et al*., 2000c).

(d) Pair-wise Comparisons. Pair-wise comparisons ask the respondent to show their strength of preference for one alternative over another (Bloom, 2010). For example, respondents might be asked to compare two environmental improvement programmes and their outcomes.

They would need to state which is preferred, and whether it is strongly, moderately, or slightly preferred to the other program (King *et al*., 2000c).

Weaknesses

In the application of choice experiments respondents have one choice among a number of alternatives (either two or more). Choice experiments' data is weakly ordered as the method only contains information on the preferred alternative. This weakness, however, can be overcome by the use of contingent ranking (Kjær, 2005). The latter requires all alternatives presented to be ranked. This creates a complete preference order, and gives information on all alternatives. Contingent ranking may have this advantage, but it can be more cognitively taxing on respondents.

The respondent, however, experiences the most demanding survey when contingent rating is used. This is because respondents not only have to show order of preference for all alternatives (such is the case with contingent ranking), but also have to indicate a level of preference for each alternative (a scale of 1 to 10).

Contingent ranking and rating methods are not in line with theory. Individuals have to make choices when surveyed that depart from real world choice contexts (Kjær, 2005). Owing to this, their use is limited in literature.

Strengths

According to Merino-Castelló (2003) only one attribute can be presented to respondents for valuation with CVM. CM has the ability to analyse more than one attribute at a time. CVM can only overcome this drawback by creating different scenarios for each attribute level; however, this would increase the costs of research (Merino-Castelló, 2003). CM also avoids multi-collinearity problems, since attribute levels are designed as orthogonal. Lastly, CM avoids response difficulties found with CVM (Merino-Castelló, 2003).

2.4.2 THE SOCIAL DISCOUNT RATE

A fundamental part of CBA is the comparison of costs and benefits that occur at different points in time. To make these costs and benefits commeasurable they are discounted to present values using a discount rate (Dinwiddy and Francis, 1996). The choice of discount rate in CBA is a well debated issue since the outcomes of the decision-making criteria are heavily influenced by its relative size (Du Preez, 2004).

The discount rate applied in a CBA has a two-fold function: on the one hand it represents the social opportunity cost of capital (SOCC), and on the other represents society's time preference in consumption rate (STPR) (Du Preez, 2004).

2.4.2.1 The Social Time Preference Rate and the Social Opportunity Cost of Capital

The discount rate relating consumption from one period to another can be described using a two-period model (Du Preez, 2004). The model has two features, namely intertemporal consumption preferences and intertemporal consumption possibilities. Intertemporal consumption possibilities are dealt with first. Consumption possibilities over the two periods, t and $(t+1)$, are described by C_t and $C_{(t+1)}$ respectively. $C_{(t+1)}$ is a function of C_t (Du Preez, 2004). What is not consumed in period t is saved and invested, which creates more possibilities for consumption in period $(t+1)$,

$$C'_{(t+1)} = \frac{dC_{(t+1)}}{dC_t} = -(1+r); r > 0 \ldots\ldots (2.12)$$

r is the consumption gained in period $(t+1)$ from the consumption sacrifices made in period t. Based on Equation 2.12, it is possible to specify the consumption possibilities available to individuals as follows:

$$C_{(t+1)} = C_0 - (1+r)C_t \ldots\ldots (2.13)$$

Demand and supply in capital markets determine the value of r in Equation 2.13, which is commonly known as the SOCC (Du Preez, 2004). The SOCC is the rate of return on the best alternative investment (of similar risk) that the proposed project displaces (Turner, Pearce and Bateman, 1993). The government borrowing rate is commonly used to reflect the SOCC, since it is long-term and risk-free (Du Preez, 2004).

The preferences of an individual with regards to his/her intertemporal consumption is examined by use of the person's utility function. If,

$$\frac{dU}{dC} > 0 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.14)$$

and

$$\frac{d^2U}{dC^2} < 0 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.15)$$

and

$$\frac{dU}{dC} \cdot \frac{C}{U} = 1 - b \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.16)$$

the person's utility function is of the form:

$$U = aC^{1-b} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.17)$$

where a and b are constants and $1 - b$ is the consumption elasticity of utility. Equation 2.17 is true for both time periods and hence:

$$U'(C_t) = (1-b)aC_t^{-b} \dots \dots \dots \dots \dots \dots \dots \dots (2.18)$$

$$U'(C_{t+1}) = (1-b)aC_{t+1}^{-b} \dots \dots \dots \dots \dots \dots \dots \dots (2.19)$$

If $C_t < C_{t+1}$, then:

$$U'(C_{t+1}) < U'(C_t) \dots \dots \dots \dots \dots \dots \dots \dots (2.20)$$

which suggests that when the person is maximising utility, the absolute value of the slope of the indifference curve (MRS) exceeds unity:

$$MRS = \frac{U'(C_t)}{U'(C_{t+1})} = (1+s); s > 0 \dots \dots \dots \dots \dots \dots \dots \dots (2.21)$$

where MRS is the marginal rate of substitution of current consumption for future consumption. The rate at which an individual would trade future consumption for more current consumption is represented by s in Equation 2.21 (society's time preference in consumption rate (STPR)) (Du Preez, 2004). In a perfect capital market where competition exists, savings rates and borrowing rates would be equal, i.e. $r = s$. However, capital markets are not perfect and therefore, due to barriers such as taxation on dividends, differences on risk and the existence of externalities, these two rates are seldom equal (Du Preez, 2004). The STPR is represented by the following equation:

$$STPR = ug + a \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.22)$$

where u is the elasticity of marginal utility of income, g is the per capita rate of growth of income, and a is the pure time preference rate (Du Preez, 2004). The first term in the above equation, u, is the rate at which the extra utility that arises from income, declines as income increases. The United Kingdom (UK) government, for example, uses a rate of one for this variable in deriving their official discount rate (HM Treasury, 2002). The future per capita output growth rate, g, for a particular country should be based on past growth rates. When g is forecast for long run values, forecasting becomes speculative in nature (Du Preez, 2004). With respect to the final term in the above equation, a (the pure time preference rate) is a rate that indicates an individual's preference for current consumption over future consumption, with the level of consumption per capita remaining constant. A value for the pure time preference rate is a point of debate (Du Preez, 2004). A value of zero is advocated, since to give the utility of future generations less weight of importance than today's is considered ethically incorrect (Du Preez, 2004).

2.4.2.2 A Composite Discount Rate

Since capital markets are imperfect, a composite discount rate composed of the STPR and the SOCC should ideally be used (Du Preez, 2004).

In order to determine this composite rate for South African public projects from first principles, the sources of government funding are examined in order to reflect both the STPR and the SOCC. There are three main funding sources, namely taxes, government borrowing and foreign aid. Taxes originate from the sacrifices made by households and companies in terms of consumption and savings. The cost of consumption sacrifices made are measured by the interest rate consumers are willing to pay to borrow, whereas savings sacrifices are measured by the foregone dividend yield and capital growth on their savings. The cost of government borrowing is measured by the interest paid on government bonds. Foreign aid does not carry an opportunity cost from a country's point of view, unless the resources were to be allocated to another source. The weighted social discount rate, i, can be estimated as follows (Du Preez, 2004):

$$i = (1-f)t[(1-s)(x_1-p)+(s)(x_2-p)]+(1-f)(1-t)(x_3-p)+f(x_4-p) \ldots\ldots\ldots. (2.23)$$

where f is the proportion of foreign funding of the total; t is the proportion of government expenditure funded through taxes paid; $1-t$ is the proportion of government expenditure funded through borrowing; s is the proportion of people's disposable income that is saved; $1-s$ is the proportion of disposable income consumed; x_1 is the average of the predominant overdraft rate on current accounts and the term lending base rate; x_2 is the average of the dividend yield and the capital growth of all listed shares on the Johannesburg Stock Exchange (JSE); x_3 is the average of the government loan stock yield and the Eskom bond rate; x_4 is the interest rate cost of foreign funding; and p is the consumer price index (inflation) (Du Preez, 2004).

2.4.3 DEALING WITH RISK AND UNCERTAINTY

Risk and uncertainty are common in every day life. Risk is defined as randomness that is measurable or quantifiable and can be described by a probability distribution. Risk can lead to an advantageous outcome, but also to a disadvantageous outcome. Uncertainty is a more fundamental form of randomness, which cannot be measured or estimated by a probability distribution. Uncertainty often stems from an infrequently occurring, discrete event. Therefore, it is very difficult to incorporate uncertainty into a CBA (Stæhr, 2006).

Undertaking a CBA without the incorporation of risk, leads to a situation where the variables in the analysis can change over time, but in a perfectly predictable way. In reality, however, risk is involved in the lifespan of the project. If the analyst takes risk into account the NPV calculation is as follows:

$$E[NPV] = E_0\left[\sum_{t=0}^{n}\frac{1}{(1+i)^t}(B_t-C_t)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.24)$$

where, $E_0[.]$ shows the mathematical expectation before the decision of whether or not to implement the project has taken place (Stæhr, 2006). The NPV in most CBA's are actually expected NPVs.

2.4.3.1 Adjusting the Expected NPV to Take Account of Risk Aversion

Several methods that adjust the calculated expected NPV to take risk aversion into account are discussed below. These methods are used to add caution when deciding to take on a project when risk and uncertainty exist. The methods are the cut-off period, risk adjusted discount rate, certainty equivalents, downward revision of benefits and upward revision of costs, the safety margin, the precautionary principle and sensitivity analysis.

(a) Cut-Off Period. There are projects that involve large costs in the early stages and benefits in the later stages. One way to reduce the risk of choosing unfavourable projects is to cut off the period of benefit flow, for example, after 3 years (Stæhr, 2006). This implies that net benefits beyond the cut-off period are assumed to have a social value of zero. On the other hand, if the period that was cut off includes large costs, this may increase the risk of accepting projects that are socially unfavourable.

(b) Risk-Adjusted Discount Rate. An upward adjustment of the discount rate is often considered in order to reduce the weight of later periods in the estimation of the expected NPV. The reasoning behind this adjustment is that it is easier to forecast nearer costs and benefit flows than ones that accrue in later periods. This method is not appropriate when the main risks and uncertainty originate from early periods.

It is also appropriate to use a decreasing discount rate if the discount rate itself is subject to risk and the time horizon is lengthy (Stæhr, 2006). When the discount rate is risky, the expected NPV is larger than the NPV calculated using the expected discount rate. The difference becomes greater as the time horizon is increased. A decreasing discount rate gives a mathematically correct E[NPV] calculation (Stæhr, 2006).

(c) Certainty Equivalents. Certainty equivalents is a tool used to adjust the expected NPV to take into account risky net benefits based on a specific welfare grounding (Stæhr, 2006). The certainty equivalent is the non-random net benefit, which would make the decision-maker unconcerned between the non-random value and the random net benefits. The certainty equivalent is smaller than the mean net benefits if the decision-maker is risk averse. The difference between the certainty equivalent and the expected net benefit is commonly known as the risk premium. The risk premium is the amount the decision-maker would be willing to pay to avoid having to take on the risk of the project (Stæhr, 2006).

(d) Downward Revision of Benefits and Upward Revision of Costs. The problem with the certainty equivalents method is that prior knowledge of the distributions of the variables entering the calculation are needed. This usually results in the net benefits being adjusted downward on an *ad hoc* basis (Stæhr, 2006). An alternative would be to adjust the expected value of certain costs upward. These adjustments may be small, if the costs and benefits are known with a large degree of certainty (this comes with experience with particular projects). However, if the project is relatively new and is based on new technology, the adjustment might be large (Stæhr, 2006).

(e) Safety Margin. The NPV should not only be positive, but if risk and uncertainty exist in the evaluation, a significant safety margin should be implemented. The expected NPV should be larger than a value decided in advance. A large positive expected NPV can be viewed as providing a suitable safety margin for accepting a project, with the implicit knowledge that the main outcome would not have changed had risk or uncertainty been included into the estimation (Stæhr, 2006).

(f) Precautionary Principle. Projects that affect the environment should incorporate the precautionary principle, since the costs of environmental damage can be irreversible. The premise behind the principle is to avoid excessive harm to the environment and to only implement projects that are more prudent. The principle can be applied by implementing *ad hoc* adjustments to costs and benefits in directions that change the expected NPV in a way that makes it less likely that a potentially environmentally harmful project is accepted, and more likely that an environmentally friendly project is accepted (Stæhr, 2006).

(g) Sensitivity Analysis. A sensitivity analysis reveals what happens to the expected NPV when a variable is changed. There are three types of sensitivity analyses that are discussed, namely gross sensitivity analysis, stress testing and Monte-Carlo simulation.

(1) Gross Sensitivity Analysis. Firstly, a baseline scenario is computed for the expected NPV (all expected values of variables are used). Then one of the variables is changed, and a new expected NPV is found. This process is carried out for all variables entering the CBA and is repeated with different changes in the variables. Hence, the alternative name of "variable-by-variable" sensitivity analysis. This analysis gives the analyst an idea of the sensitivity of the expected NPV to given changes in the considered variable (Stæhr, 2006).

(2) Stress Testing. This type of analysis involves calculating worst/best case scenarios. A baseline expected NPV is calculated using the expected values for all variables. The smallest and the largest values for each variable are entered into Equation 2.24.

These worst/best case scenarios help identify where a good or bad development of a variable affects the expected NPV most strongly. Stress testing, however, does not reveal the likelihood that a variable would take its worst/best case value. It omits the probability distributions of these scenarios (Stæhr, 2006).

(3) Monte Carlo Simulation. The above mentioned sensitivity analysis methods have several concerns for the analyst. Gross sensitivity analysis and stress testing do not assign probabilities in the experiment. Stress tests scenarios are not likely to happen in the real world, as it is generally uncommon for the variable to take on its extreme value. Lastly, both methods only take into account one variable at a time. These weaknesses can be overcome by undertaking Monte-Carlo simulation.

Monte-Carlo simulation is a computerised mathematical model that allows researchers to take risk into account in a CBA (Palisade, 2010). It provides the analyst with a range of possible outcomes and the probabilities of occurrence for any choice of action. It shows the extreme outcomes along with all possible consequences in between the extremes.

This type of simulation performs risk analysis by building models of possible results by substituting a range of values (a probability distribution) for any factor that has inherent uncertainty. Results are then calculated repeatedly, each time using a different set of random values from the probability functions. This simulation could involve thousands of calculations, depending upon the number of uncertainties and the ranges specified for them (Palisade, 2010).

2.4.4 INCORPORATING DISTRIBUTIONAL FACTORS

CBA is focused on efficiency, where a project is carried out if it has a positive NPV. This is based on a potential Pareto improvement (the Kaldor-Hicks criterion) where the winners can compensate the losers in full and at least one winner would still be better off. In reality, however, this principle is not applied, as the winners do not compensate the losers (Rosen, 2001). CBAs usually weight costs and benefits equally amongst the population of losers and gainers. Therefore, the distribution of the costs and benefits must be identified and, in some cases, incorporated into the CBA decision rules (Rosen, 2001).

The distribution issue has several dimensions: that among the people in a country, that among one country and another, and that between regions within a country.

2.4.4.1 Income Weighting and Utility Theory

Distributional weighting can be carried out in a CBA by incorporating an income weight in the NPV calculation. The costs and benefits are weighted in a manner which is more advantageous for the poorer segments of society. An unweighted NPV is calculated as follows:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \ldots \ldots \ldots (2.25)$$

In contrast, a NPV calculated using distributional weighting (Z) is estimated as follows:

$$Z = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \cdot W_j \ldots \ldots \ldots (2.26)$$

where W_j is set in order for benefits to be experienced more influentially by the losers of the project. $W_j = 1$ when no weighting is applied.

Weighting is derived from welfare theory. Diminishing marginal utility of income is the hypothesis that is utilised. The hypothesis states that when utility (U) is a function of income (Y):

$$U = U(Y) \ldots \ldots \ldots (2.27)$$

Thus, the marginal utility of income can be defined as:

$$\frac{dU}{dY} < 0 \ldots \ldots \ldots (2.28)$$

The weighting can be calculated using a ratio of the national average income $(\overline{Y})$ to the per capita income (Y_j) of the group in the study area:

$$W_j = \frac{\overline{Y}}{Y_j} \ldots \ldots \ldots (2.29)$$

If the income of the group (Y_j) is below the national average income $(\overline{Y})$, then the ratio is greater than unity with $W_j > 1$, which entails that the benefits accruing to the less well off group are more influential. However, if the income of the group (Y_j) is greater than the national average income $(\overline{Y})$, then the ratio is less than unity with $W_j < 1$, which means that the benefits accruing to the more well off group is less influential (Du Preez, 2002).

2.4.4.2 Distribution and the Nation State

Distribution must also be considered between one country and another. The weight usually assigned to benefits and costs accruing to foreigners are zero. The decision-maker who is interested in a certain group's welfare may not extend this benevolence to other nations.

Non-unity weighting represents the economy as a whole and as such, this type of weighting is not normally used for costs and benefits accruing to the state. However, extra income to the state may be considered more valuable than income to the average local citizen because the state can act as a distributor of this income (Du Preez, 2002).

2.4.4.3 Regional Distribution

The NPV of the project can be broken down according to region to obtain a regional planning balance sheet. The balance sheet provides the effects of benefits and costs upon different regions and the benefit and costs that cannot be assigned to any specific region. Given Equation 2.29 and the data relating to the project in question, the weighted net benefit for each region can be compared and the total net social benefit calculated (Du Preez, 2002).2.4.4.4 Distribution between Social Classes

The most important type of distributional weighting relates to that between various social classes in a country (Du Preez, 2002). This is particularly true for developing countries where there may be a vast gap between rich and poor.

The weighting applied should be the same as in Equation 2.29 discussed above. However, if the NPV is not weighted, the relevant transfer payments made when the project is implemented should be taken into account when making decisions regarding distribution.

2.4.5 THE TIME HORIZON OF THE PROJECT

A suitable time horizon for the CBA must be selected, that is, the time frame of benefit and cost streams must be chosen for the analysis. The time period selected should ideally be aligned to the economic life of the project (Du Preez, 2002). Often the time horizon is set by the expected useful life of any capital investments. Specialists who deal with the type of capital used in a project usually determine the time horizon. The following should be considered in the choice of time frame: assumptions regarding maintenance (this might prolong the life of the asset) or future changes, such as demographic trends in a geographical area. The discount rate is a consideration taken into account when the economic life of the project is established. High discount rates reduce the economic lifespan of the project, whereas low discount rates extend the time horizon.

Biases are possible, such as an arbitrary shortened time period, which would lower the NPV by reducing the future benefit stream, or extending the time frame far into the future may raise the NPV. However, if large future social costs are involved, then changing the time horizon would have the opposite effects on NPV (Fuguitt and Wilcox, 1999).

2.5 CBA METHODOLOGY USED IN THE TYEFU CPV ELECTRIFICATION

The CBA methodology applied in this study is discussed below. Two CBA's are carried out, namely a social CBA and a private CBA. The economic costs and benefits in the social CBA are valued at shadow prices. The private CBA values private (financial) costs and benefits at market prices. The costs were obtained from specialists in the solar industry.

The private and economic costs involved in the CBA are categorised into three categories. Firstly, the investment cost comprises the initial costs in the project (occurring at year zero) for capital expenditures (CPV modules, trackers and the balance of system costs (BOS)), transportation, the first set of batteries, training and installation. Secondly, operating and maintenance costs occur annually. Annual operating and maintenance costs consist of expenditures on labour, materials and water. In addition to the annual operating and maintenance costs, every four years operating and maintenance includes the cost to replace the battery bank. Lastly, decommissioning costs (occurring in the final year) comprise of costs to dismantle the CPV plant.

The social benefits of CPV are based on the 'with or without' principle. Without CPV, the Tyefu community would incur costs in obtaining energy for themselves. With CPV, the community avoids these costs (which are discussed in length in Chapter Three). These avoided costs are the economic benefits of CPV in the study. The private benefits are the revenue earned by the private investor who initiates the project. Income from recycling the plant's components during decommissioning, and the recycling of the batteries every four years, is considered in both private and social analysis. All estimated costs and benefits used in this analysis are expressed in 2010 domestic prices.

Externalities are identified and classified under the appropriate cost or benefit category.

The decision-making criteria used in the analysis are namely the NPV, IRR and the BCR.

The social discount rate used is a composite rate made up of the SOCC and STPR. The private discount rate is the difference between the prime lending rate and the inflation rate.

A sensitivity analysis is applied to the private CBA to test the results found by altering the discount rate and the bidding price. A sensitivity analysis is applied to the social CBA to test the results by altering the discount rate.

No distributional weighting is applied in the CBA as only one community with fairly homogeneous income levels is involved. In other words, a weight of one is attached to all Rand benefits.

The project period is from 2011 to 2035 (based on a useful life of 25 years for CPV).

2.6 APPLICATION OF COST-EFFECTIVENESS ANALYSIS

CEA is a technique for comparing the relative value of various strategies. In its most common form, the cost-effectiveness ratios of two or more projects with identical resource costs are compared and the project with the lowest ratio is preferred. The cost-effectiveness (CE) ratio for a project can be formally expressed as:

$$CE\ ratio = \frac{Resource\ cost}{Unit\ of\ effectiveness} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.30)$$

where the unit of effectiveness describes the non-monetary output produced by a project.

The final value of this ratio can be considered as the “price” of implementing a project. If the price is low enough, the new strategy can be seen as “cost-effective” (ACP, 2000).

According to ACP (2000), there are four basic steps to be followed when undertaking a CEA.

Firstly, different solutions and approaches to the problem at hand must be developed. In this first step the analyst defines the aim, focus and limitations of the project.

Secondly, the monetary costs of the project need to be calculated. In most cases, costs are calculated from society's point of view, that is, the value of all societal resources used in the project are counted as costs, regardless of who pays for these resources. The total cost over the project's life is calculated first. This figure is then discounted to a present value. The present value of total cost is then divided by the number of years that make up the project's life - this produces a cost per annum (ACP, 2000).

Thirdly, a commensurate measure of output must be specified. In the health field, for example, these outputs can be measured as lives saved, complications avoided etc. (ACP, 2000). The output over the lifespan of a project is converted to a per annum figure.

Fourthly, Equation 2.30 must be computed. A decision rule is then applied to the calculated ratio, i.e. the project with the lowest CE ratio is preferred.

An example of a CEA of alternative ways of saving lives could entail the comparison of how many lives are saved with the associated costs of doing so. More specifically, if Project A saves 10 lives per annum, Project B saves 5 lives per annum and each project costs R100 000, then the CE ratios are shown in Table 2.1 below.

Table 2.1: A CEA example

Project	Output (lives saved)	Cost	CE ratio
A	10	R100 000	R10 000/life
B	5	R100 000	R20 000/life

Thus, Project A would be chosen because it saves more lives - the cost per life saved is less under A compared to B. The CEA, therefore, shows that resources should not be allocated to a specific life-saving project if more lives could be saved by allocating resources differently.

2.7 CEA METHODOLOGY USED IN COMPARING PV AND CPV

In this study two CEAs that compares the cost-effectiveness of traditional PV to the newer CPV technology in terms of private and social values were carried out.

The costs (both PV and CPV) involved in the CEA are valued at market prices for the private CEA and are obtained from experts in the solar industry. The total cost (for each technology) over the project time horizon is calculated. These cost figures are then discounted to present value terms using the private discount rate (prime lending rate less inflation). This figure is then converted to a per annum cost. In terms of the social CEA, social costs and the social discount rate are used.

The effectiveness of both PV and CPV is computed. This is the electricity generated (output) per annum, per technology. In this study, the output is kept constant for both PV and CPV.

The decision-making criteria used in the CEA is the CE ratio, with the lowest ratio being preferred.

The project period is from 2011 to 2035 (based on a useful life of 25 years for PV and CPV).

2.8 PREVIOUS STUDIES

CPV is a relatively new technology in the solar industry. Thus, few economic studies (especially CBA and CEA) have been carried out. This section therefore has more emphasis on economic studies in general and focuses on traditional PV statistics. The following studies were reviewed in order to better understand the application of the above mentioned methodologies for CPV.

The Diakoulaki, Zervos, Sarafidis, and Mirasgedis (2001) CBA for solar water heating systems in Greece was consulted. Diakoulaki *et al*. (2001) used conventional technologies as the base case in the CBA, and compared this to solar water heaters. Benefits included were energy saving, avoided environmental damage, and job creation. Results showed positive net social benefits for solar water heating systems if substituted for electricity and diesel (not for natural gas).

Similarly, Mor, Seroussi, and Ainspan (2005) completed a CBA for large scale utilisation of solar energy (solar thermal and PV) in Israel. The study identifies the costs and benefits with regards to the deployment of solar energy in Israel. The study shows that solar technology has the ability to produce skilled employment, exportable technology, and a clean and stable energy source for Israel. The main benefits included in the study were avoided environmental damage (in the form of less tons of carbon dioxide) and employment (from construction, installation and maintenance). The main costs involved were generation costs, environmental costs and fuel switching costs. Positive net benefit streams were shown for discount rates of 5 percent (1 771.2 million US$) and 7 percent (2 057 million US$).

Borenstein (2008) investigates the market value and cost of PV electricity production. Borenstein (2008) incorporates the fact that electricity from PV technology is generated in a disproportional manner, with PV generating most of its output during peak demand periods. The results show that the timing of PV output enhances its value when the wholesale price of conventional electricity peaks with demand (this also depends on the reserve capacity in the system). Borenstein (2008) also investigates the increased value PV systems have owing to their ability to be deployed in a decentralised manner.

2.9 SUMMARY

The overview carried out in this chapter investigated several key areas in the methodologies applied in the study. Firstly, the welfare foundations of CBA were discussed. This was followed by the eight essential steps taken in applying a CBA. The practical issues encountered in CBA were then discussed. The issues covered were: the valuation of costs and benefits, the social discount rate, dealing with risk and uncertainty, incorporating distributional factors, and the time horizon of the project. The basic steps in the application of a CEA were then discussed. Lastly, previous economic studies on solar energy technologies were discussed. Chapter Three draws from this chapter, and defines the costs and benefits of the Tyefu electrification project.

CHAPTER THREE: A CLASSIFICATION OF THE COSTS AND BENEFITS OF THE TYEFU ELECTRIFICATION PROJECT

3.1 INTRODUCTION

This chapter describes the financial as well as economic costs and benefits associated with the deployment of a CPV system in the Tyefu area in the Eastern Cape. Financial costs and benefits are employed in the private CBA, whereas economic costs and benefits are employed in the social CBA. The economic costs and benefits are, where applicable, valued in terms of shadow prices. Both financial and economic costs are employed in the CEA.

3.2 PROJECT COSTS

The cost information used in this study was obtained from the Physics Department of the Nelson Mandela Metropolitan University (NMMU), Ricard Pardell (Valldoreix Greenpower), and Chris Purcell (EDG). In what follows, the financial and economic costs of the CPV system are discussed.

3.2.1 FINANCIAL COSTS

The financial costs comprise of investment costs, operating and maintenance costs, and plant decommissioning costs. Investment costs occur at the beginning of the project (the initial years of the analysis period). They consist of the planning costs incurred in the design and planning stage of the technology, capital equipment cost, land acquisition costs[22], transport costs, installation costs and training costs (Pardell, 2011; Slack, 2011). Operating and maintenance costs are the costs incurred in running the project on a day-to-day basis, and

[22] In this study, it is assumed that land acquisition costs are zero - the land necessary for the development of the CPV system is made available free of charge (it is publicly owned land (Maliti, 2010)).

include the battery replacement cost incurred to replace batteries once they have reached the end of their useful lives (Pardell, 2011). Plant decommissioning costs occur at the end of the project's life cycle. All financial costs are measured at market prices.

3.2.1.1 Investment Costs

In the case of the Tyefu CPV project, the investment costs took place during the first year of analysis. With respect to CPV technology, the investment cost was broken down into five components, namely system cost, freight and insurance, local transport, installation and training of workers.

(a) System Cost. Firstly, the system cost comprises expenditures on CPV modules, trackers and the balance of system costs (BOS).

To fully comprehend the costs associated with CPV modules, trackers and the BOS, further explanation of these components are provided below.

A CPV module's basic architecture is explained in Figure 3.1.

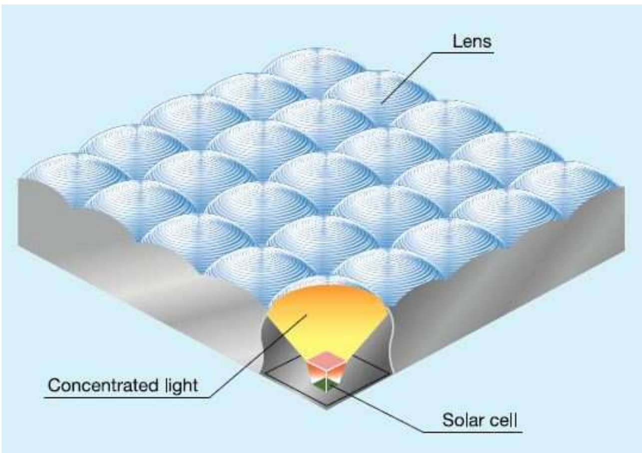

Figure 3.1: Concentrator Module Architecture

Source: Daido (2011b)

The module comprises multiple configurations (lenses) concentrating light onto the solar cells.

CPV modules are mounted onto a tracking structure that enables the modules to be aligned with the sun at all times[23]. This structure includes a dual axis and mounting structure. Figure 3.2 shows an example of a mounting structure with tracker.

Figure 3.2: Example of a Basic Mounting Structure with Tracker

Source: Daido (2011b)

Figure 3.3 illustrates the dual axis trackers that enable CPV modules to be moved both horizontally and vertically so that the sunlight absorption rate is maximised. An example of a single axis tracking system is included to illustrate the difference between the two types of tracking systems.

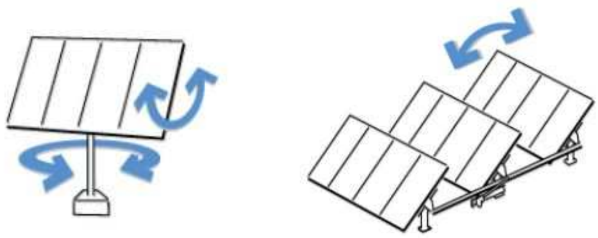

Figure 3.3: Solar Tracking Systems Dual Axis (left) and Single Axis (right)

Source: LINAK (2011)

[23] Trackers are essential for CPV, since CPV can only utilize direct radiation to be reflected and concentrated (ISFOC, 2011).

The BOS costs include the costs for cable and wiring, inverters, regulator and the initial battery bank. An inverter is a device used to convert direct current (DC) electricity to alternating current (AC) electricity. Batteries are essential for “stand-alone” or “off-grid” systems such as the one used in the study. The energy generated during the day is stored in a battery bank for use at night. A regulator's role in the system is to regulate the amount of charge coming from the CPV modules that flows into the battery bank in order to avoid the batteries being overcharged.

The entire system will be imported from Spain. The cost of the system will be converted into local terms by applying the official Euro-Rand exchange rate for the year in question.

(b) Freight and Insurance. In order to acquire the CPV plant and its components, the items must be shipped from a foreign country owing to a lack of large scale manufacturing of CPV technology in South Africa. It was assumed that the needed capital equipment would be shipped from Valencia, Spain[24] to Port Elizabeth[25]. The shipping costs include charges from both foreign and local ports, and custom duties.

(c) Local Transport Costs. Once the CPV equipment arrives at Port Elizabeth it must be transported by road to Tyefu in the Eastern Cape.

(d) Installation Costs. Upon the CPV equipment's arrival at Tyefu, the plant will need to be installed. The installation costs include costs for engineering, civil works and an Engineering Procurement and Construction (EPC) mark up. Installation times are relatively short. The 30kWp system's installation time at Tyefu would take 2 months.

(e) Training Costs. To carry out the maintenance, a team of workers would need to be assembled in the Tyefu area. This team would require training to undertake the responsibilities of maintenance of the CPV plant.

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[24] Spain is a CPV manufacturing country with ISFOC as an example of a CPV research facility.
[25] This is the closest port for Tyefu.

3.2.1.2 Operating and Maintenance Costs

The maintenance carried out on CPV systems is similar to that of conventional PV systems. The operating and maintenance of a CPV plant entails ongoing monitoring of the system. Constant monitoring is key to ensure that the system remains in operation and is a daily exercise that cannot be easily scheduled (Williams, 2011). Operating and maintenance can be subdivided into the following components.

(a) Salaries and Wages. Wages need to be paid to the workforce maintaining the Tyefu plant. The workforce comprises two unskilled labourers and one skilled labourer. The unskilled labourers would undertake routine tasks. The skilled labourer would manage the maintenance of the plant and would perform tasks that require more advanced knowledge.

(b) Battery Replacement Costs. The CPV plant in question is an off-grid plant and thus requires battery replacement on a regular basis. The replacement of the batteries is assumed to occur every 4 years provided that the batteries are well maintained. The batteries used for the system are purchased locally.

(c) Spare Parts and Lubricants Costs. Trackers are the only mechanical element in a CPV system and require simple maintenance of the gears and motors to ensure proper alignment with the sun's position (SolFocus, 2011a). This type of maintenance requires the acquisition of spare parts and lubricants. Spare parts and lubricants are purchased locally.

(d) Cleaning Costs. The modules of CPV must be washed systematically[26] to ensure optimal sunlight penetration. This implies a water cost to maintain the system. The amount of water used is negligible, however, and the water is freely available. It is thus assumed that there is no water cost in this case (Van Dyk, 2011).

[26] The timing and frequency of washing modules is highly dependent on actual weather conditions (Williams, 2011).

3.2.1.3 Decommissioning Costs[27]

The costs of decommissioning the plant occurs at the end of the project's life cycle. The decommissioning costs involved are dependent on the plant design and the decommissioning requirements. These include costs with regards to the dismantling of the constituent components of the CPV system. The dismantling of cables forms an important part of the decommissioning process. If concrete trenches are utilised to lay the cables, the dismantling costs may be high. However, if cables are passed through elevated metallic structures, the dismantling costs will be lower (Pardell, 2011). For the study it is assumed that elevated metallic structures are utilised.

3.2.2 ECONOMIC COSTS

The economic costs of the CPV system project are divided up into primary costs and secondary costs. Primary costs are those costs that are directly attributable to the project itself, whereas secondary costs are owing to the indirect effects of the project. The primary costs are used in both the social CBA and the CEA.

3.2.2.1 Primary Costs

The primary economic costs are identical to the financial costs discussed in the previous section, however they are measured differently. Unlike the financial costs, most of the economic costs of the inputs of the proposed project are not measured at their market prices. Instead, they are measured net of transfer payments (transfer payments within the national economy are eliminated from the market prices of the inputs). Value added tax (VAT), customs duty and the amount with which statutorily enforced minimum wage rates exceed the scarcity value of labour are examples of such transfers. These adjustments are discussed below.

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[27] An alternative to the decommissioning of the plant would be to revamp it, and keep it in operation if it is economically viable.

(a) Investment Cost. As mentioned before, only the CPV system is imported. Thus, to determine its economic cost the cost-insurance-freight (CIF) value is firstly determined. This value is then transformed into a local currency amount via the official Euro-Rand exchange rate. The other investment cost components that are acquired locally, namely the regulator, battery bank, local transport, installation and training, are converted into economic costs by applying the standard goods conversion factor of 0.88[28] as recommended by Mullins *et al.* (2007).

(b) Operating and Maintenance Costs. Of all the operating and maintenance costs identified in section 3.2.1.2, the following ones require transformation into economic costs: salaries and wages, battery replacement, spare parts and lubricants (as mentioned before, cleaning costs are assumed to be zero) .

1) Salaries and Wages. In order to determine the economic cost of labour for the Tyefu project a distinction is made between unskilled and skilled labour. Since the two unskilled labourers possess poor technical skills, their wages are determined via a shadow wage rate, that is, the income per worker in the region (Mullins *et al.*, 2007). This wage is usually lower than the minimum wage and is a good indication of the opportunity cost of labour. With regards to the skilled labourer, his/her wage is valued at market prices (Mullins *et al*., 2007).

2) Battery Replacement. The standard goods adjustment factor of 0.88 is applied to the market value of the batteries to arrive at the economic cost.

3) Spare Parts and Lubricants. The standard goods adjustment factor of 0.88 is applied to obtain the economic cost of the spare parts and lubricants.

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[28] This number is rounded off to two-decimal places for references in text. This is done for easy reading. The full conversion factor is 0.877193 (1/1.14). This number should be used when checking calculations.

(c) Decommissioning Costs. These costs are the same type of costs as those mentioned for the financial costs. However, a conversion factor of 0.88 is applied to arrive at the economic cost.

3.2.2.2 Secondary Costs

In addition to the primary costs, other secondary ones may also become important. A secondary cost is that the landscape may be negatively affected, in other words aesthetically and in terms of lost area available for other uses such as agriculture. CPV has a minimal optical impact on the ground. The ground beneath the CPV panel receives enough sunlight so that it may be used for agricultural purposes. The visual impact on the site location is minimal (Daido, 2011c).

3.3 PROJECT BENEFITS

In this section, the financial benefits, as well as the economic benefits, of the CPV project are discussed.

3.3.1 FINANCIAL BENEFITS

The financial benefit of the CPV project is the revenue earned by the private investor responsible for the execution of the project. This revenue is estimated as the product of the volume of electricity output and its unit value. The latter is the upper limit of the submitted price by the private investor during the bidding process.

3.3.2 ECONOMIC BENEFITS

3.3.2.1 Primary Benefits

(a) Cost Savings. In order to estimate the cost savings benefit, the 'with or without' principle is applied. The base case (the 'without' scenario) is the use of current means by Tyefu households to obtain energy. This includes the use of paraffin, liquefied petroleum gas (LPG), dry cell batteries and car batteries. These amounts and costs were defined in Chapter One (section 1.4.2.4). The project case (the 'with' scenario) is the use of CPV technology to provide the energy instead of using the current means. The primary cost savings benefit (the difference between the 'with' and 'without' scenario) of the project under consideration is thus the savings of recurring energy costs relative to the existing situation.

(b) Battery Recycling. Income is also derived from recycling batteries every four years.

(c) Decommissioning. Income is also derived from the recycling of the constituent parts of the CPV plant upon decommissioning. Recycling of the plant's components occurs at the end of its life cycle.

Shadow prices must also be applied to the primary economic benefits. The conversion factor is 0.88, since VAT is the only transfer payment that applies to the purchase of the current means of energy generation and recycling income.

3.3.2.2 Secondary Benefits

Unlike, fossil fuel-based forms of power generation, CPV systems do not emit any GHGs during power generation. This benefit is insignificant, given the size of the study area, and is thus not included in the analysis (SolFocus, 2011b).

3.4 SUMMARY

Chapter Three described all the costs and benefits taken into account in the study. Firstly, the project costs were described starting with the financial costs. Thereafter, the economic costs were explained and how the market prices were converted to economic prices described. Lastly, the project benefits were described. The primary and secondary benefits were given. The defined costs and benefits, both financial and economic, are employed in the economic assessment in Chapter Four.

CHAPTER FOUR: AN ECONOMIC ANALYSIS OF THE TYEFU ELECTRIFICATION PROJECT

4.1 INTRODUCTION

The methodologies explained in Chapter Two, and the costs and benefits defined in Chapter Three, are applied in this chapter. Firstly, the different discount rates applied to the respective CBAs and CEAs, are derived. Hereafter, the decision-making criteria are applied to determine the social and private desirability of the Tyefu electrification project. A sensitivity analysis is carried out on certain chosen variables. Two CEAs are conducted before concluding remarks end the chapter.

4.2 DISCOUNT RATES

In order to evaluate the project's desirability from both a social and a private perspective, the applicable discount rates for each case were calculated. The social discount rate is explained first, followed by the private discount rate.

4.2.1 SOCIAL DISCOUNT RATE

The social discount rate derived is based on the composite rate explained in Chapter Two (see section 2.4.2.2). The equation (Equation 2.23) used in Chapter Two is repeated here to aid the explanation. The composite social discount rate, i, can be estimated as follows:

$$i = (1-f)t[(1-s)(x_1 - p) + (s)(x_2 - p)] + (1-f)(1-t)(x_3 - p) + f(x_4 - p)$$

where:

f = proportion of foreign funding of total;

t = proportion of government expenditure funded through taxes paid;

$1-t$ = proportion of government expenditure funded through borrowing;

s = proportion of people's disposable income that is saved;

$1-s$ = proportion of disposable income consumed;

x_1= average of the predominant overdraft rate on current accounts and the term lending base rate;

x_2 = average of dividend yield and the capital growth of all listed shares on the Johannesburg Stock Exchange (JSE);

x_3 = average of the government loan stock yield and the Eskom bond rate;

x_4 = interest rate cost of foreign funding;

p = consumer price index (inflation) (Du Preez, 2004).

Data was gathered for the above mentioned variables for the period 2006 to 2010. Table 4.1 shows the cost of government borrowing, the cost of household consumption borrowing, the return on savings and the annual inflation rate for the period (2006 to 2010). Table 4.2 shows the calculation of weights t and $1-t$, and Table 4.3 shows the calculation of weights s and $1-s$.

Table 4.1: Cost of Government Borrowing, Cost of Household Consumption Borrowing, the Return on Savings and the Annual Inflation Rate (2006-2010)

Cost of government borrowing				Cost of household consumption borrowing			Return on Savings			
Year	Government stock - yields on loan stock traded on the bond exchange (10 years and over), % (a)	Eskom Bond Yield, % (b)	Average yield, % $\frac{(a)+(b)}{2}$ X3	Predominant overdraft rate on current accounts (c)	Long-term lending base rate (Hire-purchase credit),% (d)	Average rate, % $\frac{(c)+(d)}{2}$ X1	Dividend yield (e)	Capital growth % (f)	Average rate, % $\frac{(e)+(f)}{2}$ X2	Average annual inflation rate as measured by consumer price index, %
2006	7.81	8.91	8.36	13.76	11.12	12.44	2.41	35.6	19.01	3.1
2007	8.29	11.48	9.98	14.96	12.78	13.87	2.29	21.5	11.90	5.0
2008	7.82	11.45	9.64	15.16	14.53	14.85	3.16	-33.4	-15.12	11.5
2009	9.03	9.49	9.26	13.78	11.95	12.86	3.3	24.8	14.05	6.4
2010	8.38	8.99	8.69	10.75	10.18	10.47	2.16	14.4	8.28	2.9

Source: SARB (2010)

Table 4.2: The Calculation of Discount Rate Weights t and $1-t$

Year	Government borrowing requirement R millions (a)	Government revenue R millions (b)	Total R millions $(c)=(a)+(b)$	Borrowing proportion $\frac{(a)}{(b)}$ $(1-t)$	Tax revenue proportion $\frac{(b)}{(c)}$ (t)
2006	6 868	402 463	409 331	0.017	0.983
2007	-6 049	470 168	464 119	-0.013	1.013
2008	-16 584	547 977	531 393	-0.031	1.031
2009	13 065	595 972	609 037	0.021	0.979
2010	132 233	570 565	702 798	0.188	0.812

Source: SARB (2010)

Table 4.3: The Calculation of Discount Rate Weights s and $1-s$

Year	Final consumption expenditure R millions (a)	Gross savings R millions (b)	Gross national disposable income $(c)=(a)+(b)$	Final consumption expenditure proportion $\frac{(a)}{(b)}$ $(1-s)$	Gross savings proportion $\frac{(b)}{(c)}$ (s)
2006	1 116 315	254 196	1 370 511	0.815	0.185
2007	1 264 726	287 680	1 552 406	0.815	0.185
2008	1 398 236	350 846	1 749 082	0.799	0.201
2009	1 456 089	372 826	1 828 915	0.796	0.203
2010	1 575 420	438 094	2 013 514	0.782	0.218

Source: SARB (2010)

Using the above equation and Tables 4.1, 4.2 and 4.3, the real social discount rate was estimated at 5.97 percent per annum.

4.2.2 PRIVATE DISCOUNT RATE

The private discount rate was determined as the difference between the prime lending (overdraft) rate and the consumer price index over the period 2006 to 2010 (South African Reserve Bank (SARB), 2010). Table 4.4 below shows the data used for the calculation of the private discount rate.

Table 4.4: Data for the Derivation of Private Discount Rate

Year	Prime overdraft rate %	Inflation rate %
2006	11.17	3.1
2007	13.17	5.0
2008	15.13	11.5
2009	11.71	6.4
2010	9.83	2.9

Source: SARB (2010)

The private discount rate was calculated to be 6.42 percent per annum.

4.3 PRIVATE COST BENEFIT ANALYSIS

A private CBA of the Tyefu electrification project is considered below. The costs and benefits mentioned are measured at their market prices.

4.3.1 PRIVATE COSTS

The private costs include the initial investment cost, operating and maintenance costs, and decommissioning costs.

4.3.1.1 Investment Cost

Of all the capital equipment, only the system (modules, trackers and inverters) is imported – the regulator and battery bank are acquired locally. The cost of the system was estimated at R257 305.54, as follows:

System cost=(Euro/Wp X Rand/Euro exchange rate) X system size

This estimation is shown in Table 4.5 below.

Table 4.5: Derivation of the System Cost

Cost component	**Euro/Wp** $(\boldsymbol{a})$	**Rand/Euro** $(\boldsymbol{b})$	**Rand/Wp** $(\boldsymbol{c}) = (\boldsymbol{a}) \times (\boldsymbol{b})$	**System size (Wp)** $(\boldsymbol{d})$	**Local cost (R)** $(\boldsymbol{e}) = (\boldsymbol{c}) \times (\boldsymbol{d})$
System	0.88	9.71	8.58	30 000	257 305.54

The regulator (R40 000) and 96 batteries (R96 000) are purchased locally. Local transport consists of a fee of R8950 per container (one container is used) and a fuel surcharge of 5.3 percent. Installation costs amount to R217 675.24 and training costs amount to R10 000. Insurance and freight cost for the private analysis includes customs duties (R80 306.85) and customs VAT (R93 691.36) among other charges imposed by both local and foreign ports. Table 4.6 below gives the break-down of freight and insurance costs.

Table 4.6: Freight and Insurance Cost Break-Down

	Charge description	Amount (R)
Pre carriage:	Origin documentation fee	485.67
	Handling fee	1 651.26
	Export additionals	310.83
	Port security charge	48.57
	Sub total	**2 496.32**
Main carriage:	Ocean freight	7 203.58
	BAF bunker adjustment factor	4034.00
	ISPS carrier security charge	64.83
	Logistics fee	194.27
	Sub total	**11 496.69**
On carriage:	Terminal handling charge-destination	1 073.00
	Cargo dues	2 119.14
	Vessel agents fee	375.00
	Vessel agents release fee	250.00
	Cartage plz city limits	1 336.00
	Fuel surcharge	59.18
	CTO fee	120.00
	Insurance fee	3414.60
	Sub total	**8746.92**
Customs:	Customs duties	80 306.85
	Customs VAT	93 691.36
	Sub total	**173998.21**
	Total disbursements and charges	**196 738.14**
	Documentation fee	350.00
	Agency fee	6 948.69
	Finance fee	2 878.74
	Total Shenker handling fees	**10 177.43**
	Total estimate	**206 915.57**

Source: Emery (2011)

Table 4.7 below gives the break down and derivation of the private investment cost.

Table 4.7: Private Investment Cost Derivation

Cost component	Private cost (R)
System	257 305.54
Regulator	40 000.00
Batteries (96 batteries)	96 000.00
Insurance and freight	206 915.57
Local transport	9 424.35
Installation	217 675.24
Training	10 000.00
Total	**837 320.69**

Source: Emery (2011); Pardell (2011)

The total investment cost is calculated to be R837 320.69.

4.3.1.2 Operating and Maintenance

The operating and maintenance cost consists of salaries and wages (for one skilled and two unskilled labourers), battery replacement cost, and expenditure on spare parts and lubricants.

The wage rate for both skilled and unskilled labour was calculated from the 2007 Labour Force Survey (LFS) (Statistics South Africa 2007). An inflation factor was then applied to these wages in order to calculate the 2010 figures. The average annual wages for two unskilled labourers (who carry out routine maintenance) amounted to R47 553.60. The average annual wage of one skilled labourer (who carries out more advanced tasks) amounted to R80 478.22. The second component of operating and maintenance costs is replacement equipment, spare parts and lubricants (purchased locally) and this amounted to R41 968.18 annually. Lastly, an off-grid system requires a battery bank (purchased locally) to store energy captured. Batteries need to be replaced, on average, every 4 years. This entails an initial set of 96 batteries, and six periods of replacement over the lifespan of the CPV plant.

The battery replacement cost is R96 000 every four years. Table 4.8 below gives a breakdown of the operating and maintenance cost with battery replacement.

Table 4.8: Cost Components of Operating and Maintenance with Battery Cost

Operating and maintenance component	**Market price (R) per annum**
Skilled labour	80 478.22
Unskilled labour	47 553.60
Spare parts	41 968.18
Batteries	96 000.00
Total	**266 000.00**

Source: Pardell (2011); Statistics South Africa (2007)

The total operating and maintenance cost is R266 000 (Table 4.8) every four years during battery replacement, and is R170 000 (R266 000 - R96 000) every year without replacement.

4.3.1.3 Decommissioning Cost

The costs for decommissioning of the Tyefu CPV plant are the costs for dismantling the tracking structure and cables. This cost equals R14 569.96.

4.3.2 PRIVATE BENEFITS

The main financial income stream is the revenue from the sale of electricity. The electricity output is expected to be 30 300kWh per year. Using the current upper limit for CPV in the bidding process of R2.85/kWh, the expected revenue from the sale of electricity is R86 355 per annum.

Other revenue included in the analysis is recycling income earned at the end of the CPV system's life cycle, during decommissioning. The income from recycling the glass, aluminium and steel of the CPV plant is calculated to be R12 084.60. Table 4.9 below gives a breakdown of this income.

Table 4.9: A Breakdown of the Income from Recycling the CPV Plant

Component	Mass (kg)	R/kg	Private income (R)
Glass	810	0.22	178.20
Aluminium	600	10.50	6 300
Steel	2190	2.56	5 606.40
Total			**12 084.60**

Source: Goosen (2011)

Recycling income is also earned every four years when batteries are recycled. Each battery weighs 127kg, the entire battery is recycled (Goosen, 2011). This is multiplied by 96 batteries to give a total mass of 12 192 kg. The income received every four years from the batteries is R55 473.60 (12 192 kg × R4.55/kg (Goosen, 2011)).

4.3.3 SUMMARY RESULTS OF APPLYING THE CBA DECISION CRITERIA

The above mentioned costs and benefits along with the private discount rate are used to estimate the NPV, IRR and BCR. These results are summarised in Table 4.10 below.

Table 4.10: Summary Results of Private CBA Decision Criteria

CBA criteria (at private discount rate of 6.42%)		
NPV (R)	**IRR (%)**	**BCR**
-2 046 629.01	Undefined	0.365

The NPV is negative, the IRR is undefined[29] and the BCR is less than unity. These results show that the project is not feasible for a private investor.

4.3.4 SENSITIVITY ANALYSIS

The following sensitivity analysis investigates the effects of changes in the private discount rate and changes in the bidding price offered on the decision-making criteria.

4.3.4.1 Discount Rate

The derived private discount rate of 6.42 percent, was revised upwards and downwards by 2 percent and 4 percent. The results are shown below in Table 4.11.

Table 4.11: Sensitivity Analysis - Discount Rate

	CBA Decision- Making Criteria	
Discount rate(%)	**NPV (R)**	**BCR**
2.42 (-4%)	- 2 640 006.58	0.423
4.42(-2%)	- 2 297 030.96	0.404
6.42	-2 046 629.01	0.365
8.42(+2%)	- 1 860 022.39	0.369
10.42(+4%)	- 1 718 182.17	0.353

The changes in the discount rate do not significantly change the decision-making criteria. All results remain negative.

[29] There is no sign change in the net benefit flow (Appendix A) – it remains negative. Thus an IRR cannot be calculated under these conditions.

4.3.4.2 Bidding Price Change

The revenue earned by the Tyefu electrification project is dependent on the bidding price given during the tender process. A sensitivity analysis was conducted by varying the upper limit of the bidding price, namely R2.85/kWh. The price was increased by 200 percent, 250 percent, and 300 percent. The results of the sensitivity analyses are shown below in Table 4.12.

Table 4.12: Sensitivity Analysis - Bidding Price Change

		CBA Decision-Making Criteria		
Bidding price (per kWh)	**Revenue (pa) (R)**	**NPV (R)**	**IRR(%)**	**BCR**
R5.70 (200%)	172710.00	-913 476.78	Undefined	0.726
R7.13 (250%)	215887.50	-346 900.66	1%	0.896
R8.55 (300%)	259065.00	219 675.45	9%	1.066

All three decision criteria become favourable when the bidding price is increased by 300 percent (R8.55/kWh).

4.4 SOCIAL COST BENEFIT ANALYSIS

4.4.1 ECONOMIC COSTS

The economic costs include the same categories as for the private CBA.

4.4.1.1 Investment Cost

As mentioned before, of all the capital equipment, only the system is imported – the regulator and battery bank are acquired locally. The standard CIF shadow pricing method was followed in this case. The cost of the system (R257 305.54) was calculated in the same way as in Table 4.5. The insurance and freight amounted to R32 917.36. This amount was net of customs duties and customs VAT of R173 998.21.

The CIF value (already converted to local currency value) was estimated to be R290 222.90 (R257 305.54 +R32 917.36).

The market prices of locally acquired capital components (regulator and batteries), local transport, installation, and training were transformed into shadow prices by applying a standard conversion factor of 0.88 as recommended by Mullins *et al.* (2007). These conversions are shown in Table 4.13 below.

Table 4.13: Derivation of Shadow Prices for Investment Cost Components

Cost component[30]	Market price (R)	Conversion factor	Economic cost (R)
Regulator	40 000.00	0.88	35 087.72
Batteries[31]	96 000.00	0.88	84 210.53
Local transport	9 424.35	0.88	8 266.97
Installation	217 675.24	0.88	190 943.19
Training	10 000.00	0.88	8 771.93
Total	**373 099.59**	**0.88**	**327280.34**

[30] All cost components relate to a system size of 30 000 Wp.
[31] 96 batteries are required for electricity storage

The components of the total economic investment cost are shown in Table 4.14 below.

Table 4.14: Total Economic Investment Cost

Economic cost component	**R**
System (CIF)	290 222.90
Regulator	35 087.72
Batteries	84 210.53
Local transport	8 266.97
Installation	190 943.19
Training	8 771.93
Total	**617 503.24**

4.4.1.2 Operating and Maintenance Cost

The economic operating and maintenance cost includes the same components as the private operating and maintenance cost. Salaries and wages for labour need to be adjusted to reflect the scarcity value of the resource. The conversion factor of the market wage rate for unskilled labour in the Eastern Cape is 0.7 for urban areas, and 0.46 for non-urban areas (Mullins *et al.*, 2007). The average annual wages for two unskilled labourers amounted to R21 874.66 (R47553.60 × 0.46). The average annual wage for one skilled labourer was calculated to be R80 478.22 (R80 478.22 × 1). After applying the standard goods conversion factor of 0.88, the spare part and lubricant costs, and the battery replacement cost respectively amounted to R36 814.19 (R41 968.18 × 0.88) and R84 210.53 (R96 000 × 0.88). Table 4.15 shows the derivation of the economic operating and maintenance cost with battery replacement.

Table 4.15: Economic Cost Derivation of Operating and Maintenance with Battery Cost

Operating and maintenance component	Market price (R) per annum	Conversion factor	Economic cost (R) per annum
One skilled labourer	80 478.22	1.00	80 478.22
Two unskilled labourers	47 553.60	0.46	21 874.66
Spare parts and lubricants	41 968.18	0.88	36 814.19
Batteries	96 000.00	0.88	84 210.53
Total	**266 000.00**		**223 377.60**

Source: Pardell (2011); Statistics South Africa (2007)

The total economic operating and maintenance cost is R223 377.60 every four years, and is R139 167.07 (R223 377.60 - R84 210.53) every year without battery replacement.

4.4.1.3 Decommissioning Cost

The economic decommissioning cost amounts to R12 780.67 (R14 569.96 × 0.88), after applying the conversion factor of 0.88 (Mullins *et al.*, 2007).

4.4.2 ECONOMIC BENEFITS

4.4.2.1 Primary Benefits

The savings of recurring energy costs relative to the existing situation for 84 households, amounted to R201 137.04 annually (Purcell, 2011) (see section 1.4.2.4). The disaggregated cost savings are shown in Table 4.16 below.

Table 4.16: Disaggregated Cost Savings

Component	Cost per household per annum (R) (a)	Number of households (b)	Total (R) $(c) = (a) \times (b)$
Paraffin	639.24	84	53 696.43
Car battery	333.44	84	28 008.95
Dry cell batteries	902.26	84	75 790.14
LPG	854.77	84	71 800.71
Total	**2 729.72**		**229 296.20**

Source: Purcell (2011)

The total cost savings amount was converted into an economic benefit by applying the standard conversion factor (R229 296.20 × 0.88 = R201 137).

The economic benefit from recycling the glass, aluminium and steel of the CPV plant is calculated to be R10 600.53 (R156.32 + R5 526.32 + R4917.89). The income from the recycling of batteries every four years is R48 661.05. Table 4.17 shows the income from recycling.

Table 4.17: Income from Recycling the CPV Plant and Batteries

Component	Mass (kg)	R/kg	Private income (R)	Conversion factor	Economic income (R)
Glass	810	0.22	178.20	0.88	156.32
Aluminium	600	10.50	6 300.00	0.88	5 526.32
Steel	2190	2.56	5 606.40	0.88	4 917.89
Battery	12 192	4.55	55 473.60	0.88	48 661.05

4.4.2.2 Secondary Benefits

A primary secondary benefit is that CPV systems do not emit GHGs. However, the benefit from the decreased emissions by the 84 households is considered negligible, and is thus not included in the analysis (Van Dyk, 2011).

4.4.3 SUMMARY RESULTS OF APPLYING THE DECISION MAKING CRITERIA

The above mentioned costs and benefits along with the social discount rate are used to estimate the NPV, IRR and BCR. These results are summarised in Table 4.18 below.

Table 4.18: Summary Results of Social CBA Decision Criteria

	CBA criteria (at social discount rate of 5.97%)	
NPV (R)	**IRR (%)**	**BCR**
125 616.64	8	1.045

The reported NPV is positive, the IRR is greater than the social discount rate and the BCR is greater than 1. Taking all decision-making criteria into account, the CPV project, is socially desirable. It is thus an improvement in society's welfare, and would be recommended to be undertaken from a social perspective.

4.4.4 SENSITIVITY ANALYSIS

The following sensitivity analysis investigates changes in the social discount rate.

4.4.4.1 Discount Rate

The derived social discount rate of 5.97 percent, was revised upwards and downwards by 2 percent and 4 percent respectively. The results are shown below in Table 4.19.

Table 4.19: Sensitivity Analysis - Discount Rate

	CBA Decision-Making Criteria[32]	
Discount rate	**NPV (R)**	**BCR**
1.97 (-4%)	482 910.19	1.092
3.97% (-2%)	276 209.70	1.061
5.97%	125 616.64	1.045
7.97% (+2%)	13 618.10	0.993
9.97% (+4%)	-71 349.59	0.958

In terms of the NPV, the project becomes socially undesirable for an upward revision of 4 percent in the social discount rate.

4.5 COST-EFFECTIVENESS ANALYSIS

In this section the cost-effectiveness of CPV and PV is compared. The cost-effectiveness (CE) ratios calculated have identical denominators since the annual output for both technologies are identical - both CPV and PV systems deliver 30 300kWh per annum. This output is based on the demand of the given case study. Two types of CEA were carried out, one relying on private costs (see section 4.3.1) and the other on economic costs (see section 4.4.1).

[32] The IRR is not reported here, as a change in the discount rate does not affect it. The IRR is independent of the discount rate, and remains at 8%.

System, installation, and dismantling costs set the technologies apart in terms of cost. The module cost for PV is significantly larger than CPV. Other PV components are also more expensive than CPV, such as the dual axis tracker and the inverter. However, the installation cost for PV is much lower than CPV's. These cost differences are shown in Table 4.20.

Table 4.20: Cost Differences between CPV and PV

	PV **R/Wp**	**CPV** **R/Wp**
Module	12.63	5.46
Dual-axis tracking	1.94	1.22
Inverter	2.91	1.90
System	**17.48**	**8.58**
Installation	2.33	7.26
Dismantling	0.97	0.49

Table 4.21 below gives a comparison of the cost components for each technology.

Table 4.21: Comparison of PV and CPV Cost Components

Cost component	Private		Economic	
	PV Total	CPV Total	PV Total	CPV Total
System	524 518.65	257 305.54	524 518.65	257 305.54
Regulator	40 000.00	40 000.00	35 087.72	35 087.72
Batteries	96 000.00	96 000.00	84 210.53	84 210.53
Freight and insurance	206 915.57	206 915.57	32 917.35	32 917.35
Local transport	9 424.35	9 424.35	8 266.97	8 266.97
Installation	69 935.82	217 675.24	61 347.21	190 943.19
Training	10 000.00	10 000.00	8 771.93	8771.93
Total investment	**956 794.39**	**837 320.69**	**755 120.37**	**617 503.24**
Operating and maintenance:				
With battery	**266 000.00**	**266 000.00**	**223 377.60**	**223 377.60**
Without battery	**170 000.00**	**170 000.00**	**139 167.07**	**139 167.07**
Decommissioning:				
Dismantling	**29 139.93**	**14 569.96**	**25 561.34**	**12 780.67**

The private CEA uses the private discount rate of 6.42 percent, whereas the social CEA uses the social discount rate of 5.97 percent. The CE ratios based on private costs are:

$$CE\ ratio_{PV} = \frac{Resource\ cost}{Unit\ of\ effectiveness} = \frac{R132\ 964.75}{30300kWh} = R4.39/kWh$$

$$CE\ ratio_{CPV} = \frac{Resource\ cost}{Unit\ of\ effectiveness} = \frac{R128\ 251.33}{30300kWh} = R4.23/kWh$$

The CE ratios based on social costs are:

$$CE\ ratio_{PV} = \frac{Resource\ cost}{Unit\ of\ effectiveness} = \frac{R111\ 659.09}{30300kWh} = R3.69/kWh$$

$$CE\ ratio_{CPV} = \frac{Resource\ cost}{Unit\ of\ effectiveness} = \frac{R106\ 250.84}{30300kWh} = R3.51/kWh$$

The private CEA shows that CPV is more cost effective than PV, with a CE ratio of R4.23, compared to PV's CE ratio of R4.39. The same result occurs for the social CEA, with CPV having a CE ratio of R3.51, compared to PV's CE ratio of R3.69.

4.6 CONCLUSION

In terms of the private CBA, the NPV and BCR showed that the CPV project in Tyefu is not desirable form a private investor’s perspective. The IRR could not be calculated owing to no sign change in the net benefit profile. The main finding for the private CBA is that the revenue earned per kWh is too low and does not cover the large costs involved in the project. Therefore, a sensitivity analysis of the current bidding price of R2.85/kWh was undertaken. It was found that a bidding price between R7.13/kWh (250% increase) and R8.55/kWh (300% increase) makes the project desirable for the private investor. Similarly, a sensitivity analysis carried out on the private discount rate showed no significant changes in the decision-making criteria.

The CPV project, however, is desirable from a social perspective. In terms of the social CBA all three decision-making criteria show that the project is socially desirable.

Hereafter, two CEAs were carried out to compare CPV to traditional PV (in terms of private and social costs). The results showed that CPV had a lower CE ratio, for both private and social analysis, and was thus more cost effective than PV.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

South Africa's energy policymakers face two challenges: first, excessive use of fossil fuels (predominately coal) in generating electricity and its contributory role in adversely affecting the environment, and second, addressing the backlog of electricity provision to many rural, previously disadvantaged communities. In consideration of these two problems, the government has committed itself through the White Paper on Renewable Energy to provide renewable energy to rural communities.

The purpose of this study was to evaluate the economic feasibility of one such renewable energy option, namely CPV. The study area chosen for the case study was a settlement, named Tyefu, consisting of five villages in the Eastern Cape province of South Africa.

Economic feasibility of the CPV project in Tyefu was estimated via two CBAs and two CEAs. A social CBA was undertaken to investigate the project's desirability from society's perspective, and a private CBA was carried out to investigate the project's feasibility from an investor's point of view. Additionally, two CEAs were carried out that compared the cost-effectiveness of traditional PV to the newer CPV technology in terms of private and social values.

The main results were favourable in terms of the social CBA, but unfavourable for the private CBA. The social CBA yielded a NPV of R125 616.64, an IRR of 8 percent and a BCR of 1.045. The private CBA yielded a NPV of R-2 046 629.01 and a BCR of 0.365. Lastly, two CEAs, one based on private costs and one based on social costs, showed that CPV is the more cost effective choice. CPV has a private CE ratio of R4.23/kWh compared to PV's CE ratio of R4.39/kWh. Likewise, the social CEA for CPV has a CE ratio of R3.51/kWh compared to PV's CE ratio of R3.69/kWh.

It can thus be deduced that CPV rollout appears to be socially efficient on a small scale according to the social CBA. It can be concluded the project is not feasible in terms of a private investor undertaking. The benefit (income received per kWh) in the private analysis is too small to outweigh the costs of implementing and running a CPV plant in Tyefu. However, CPV may be feasible privately for large scale applications.

Currently the maximum revenue investors can earn from CPV is R2.85/kWh. For a small plant of Tyefu's size, this is not feasible for an investor and is not a strong enough incentive to undertake projects of this kind.

5.2 RECOMMENDATIONS

Taking the findings and conclusions into account, the following recommendations are made:

1. The maximum bidding price of R2.85/kWh is not a great enough incentive for private investors to undertake the CPV project. It is thus recommended that policymakers take this into consideration when formulating policy, by increasing the maximum bidding price for this technology. The sensitivity analysis of the bidding price showed that the present bidding price of R2.85/kWh needs to be increased in the range of 250 percent (R7.13/kWh) and 300 percent (R8.55/kWh) for a great enough incentive to exist for private investors.

2. The social CBA showed that the CPV project is socially desirable. It is recommended that government undertake CPV projects of this kind, as it is a socially desirable allocation of resources.

3. The alternative to CPV is traditional PV. If government were to pursue these types of projects, it is recommended that CPV be implemented, as it is more cost effective than PV.

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APPENDIX A: TIME PROFILE OF PRIVATE COSTS AND BENEFITS

Year	Costs					Private Benefits			Net Benefit
	Capital	O&M	Dismantling	Batteries	Total	REFIT	Recycling	Total	
0	837320.69	141666.66			978987.36	71962.5		71962.50	-907024.86
1		170000			170000	86355		86355	-83645.00
2		170000			170000	86355		86355	-83645.00
3		170000			170000	86355		86355	-83645.00
4		170000		96000	266000	86355	55473.60	141828.60	-124171.40
5		170000			170000	86355		86355	-83645.00
6		170000			170000	86355		86355	-83645.00
7		170000			170000	86355		86355	-83645.00
8		170000		96000	266000	86355	55473.60	141828.60	-124171.40
9		170000			170000	86355		86355	-83645.00
10		170000			170000	86355		86355	-83645.00
11		170000			170000	86355		86355	-83645.00
12		170000		96000	266000	86355	55473.60	141828.60	-124171.40
13		170000			170000	86355		86355	-83645.00
14		170000			170000	86355		86355	-83645.00
15		170000			170000	86355		86355	-83645.00
16		170000		96000	266000	86355	55473.60	141828.60	-124171.40
17		170000			170000	86355		86355	-83645.00
18		170000			170000	86355		86355	-83645.00
19		170000			170000	86355		86355	-83645.00
20		170000		96000	266000	86355	55473.60	141828.60	-124171.40
21		170000			170000	86355		86355	-83645.00
22		170000			170000	86355		86355	-83645.00
23		170000			170000	86355		86355	-83645.00
24		170000		96000	266000	86355	55473.60	141828.60	-124171.40
25		170000	14569.9625		184569.9625	86355	12084.60	98439.60	-86130.36
NPV					**3 334534.67**			**1 215 943.16**	**-2 046 629.01**

APPENDIX B: TIME PROFILE OF SOCIAL COSTS AND BENEFITS

Year	Costs					Benefits						Net Benefit
	Capital	O&M	Dismantling	Batteries	Total	Paraffin	LPG	Dry-Cell	Car Batteries	Recycling	Total	
0	617503.2	115972.55			733475.79	39251.78	52485.90	55402.15	20474.38		167614.20	-565861.59
1		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
2		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
3		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
4		139167.07		84210.53	223377.60	47102.13	62983.08	66482.58	24569.25	48661.05	249798.09	26420.50
5		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
6		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
7		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
8		139167.07		84210.53	223377.60	47102.13	62983.08	66482.58	24569.25	48661.05	249798.09	26420.50
9		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
10		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
11		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
12		139167.07		84210.53	223377.60	47102.13	62983.08	66482.58	24569.25	48661.05	249798.09	26420.50
13		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
14		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
15		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
16		139167.07		84210.53	223377.60	47102.13	62983.08	66482.58	24569.25	48661.05	249798.09	26420.50
17		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
18		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
19		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
20		139167.07		84210.53	223377.60	47102.13	62983.08	66482.58	24569.25	48661.05	249798.09	26420.50
21		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
22		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
23		139167.07			139167.07	47102.13	62983.08	66482.58	24569.25		201137.04	61969.98
24		139167.07		84210.53	223377.60	47102.13	62983.08	66482.58	24569.25	48661.05	249798.09	26420.50
25		139167.07	12780.67		151947.74	47102.13	62983.08	66482.58	24569.25	10600.53	211737.57	59789.83
NPV					**2 762521.73**						**2 888 138.37**	**125 616.64**

APPENDIX C: COSTS OF USEFUL ENERGY

	COSTS OF USEFUL ENERGY													
1. Fuel	**Elec**	**Wood**	**Charcoal**	**Kerosene**	**LP Gas**	**SHS FBE**	**Elec**	**Kerosene**	**LP Gas**	**Kerosene**	**SHS Govt**	**Car Batts**	**Candles**	**Dry Batts**
2. Unit of sale	*[kWh]*	*[kg]*	*[kg]*	*[litre]*	*[kg]*	*kWh*	*[kWh]*	*[litre]*	*[kg]*	*[litre]*	*[kWh]*	*[Batt 80Ah]*	*[pkt]*	*(4 x AA)*
3. End use	*Elec*	*Cooking*	*Cooking*	*Cooking*	*Cooking*	*Elec*	*CFL light*	*fridge*	*fridge*	*lighting*	*Elec*	*per chrge*	*lighting*	*small appl.*
4. Price [ZAR] (incl VAT)	0.90	2.00	4.00	11.00	17.00	9.00	0.90	11.00	17.00	11.00	53.00	15.00	5.00	15.00
5. Gross energy content [MJ]	3.6	17	27	37	49	18.9	3.6	37	49	37	18.9	2.8	20.7	0.03
6. Conversion to useful energy	90%	39%	40%	62%	78%	90%	40%	40%	40%	11%	90%	95%	2%	95%
7. Equiv ZAR/kWh useful energy	1.00	1.10	1.33	1.74	1.60	1.90	2.25	2.67	3.12	9.81	11.21	21	48	1,826
8. Equiv USD/kWh useful energy	0.14	0.16	0.19	0.25	0.23	0.27	0.32	0.38	0.45	1.40	1.60	2.93	6.90	260.86

Source: Purcell (2011)