An Economic Analysis of the Production, Distribution and Use of Concentrator Photovoltaic Technology in South Africa: A Case Study

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Abstract

The primary aim of this study was to determine the economic viability, from both a social and private perspective, of implementing CPV technology in South Africa. A rural, previously disadvantaged community in the Eastern Cape (Tyefu) was chosen as the study site.

To meet the primary aim, both a social and a private cost benefit analysis (CBA) were carried out. The social analysis found that the project was not viable. The private CBA showed that CPV was also not viable for a potential private investor.

A secondary aim of this study was to determine whether CPV is more cost effective when compared to conventional PV.

To meet the secondary aim a cost effectiveness analysis (CEA) was carried out. A CEA concluded that CPV was more cost effective than PV.

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

1. Introduction

CPV is a relatively new renewable energy among the mix of existing technologies. CPV uses optic elements (such as lenses) to concentrate sunlight onto cells. CPV is more efficient than conventional photovoltaics (PV). Owing to the light being concentrated, the cells in CPV use less silicon, this makes them more economical in comparison to conventional PV cells. CPV is a technology that operates well in regions with high solar radiation. South Africa is particularly well suited for this technology with average solar radiation levels ranging from 4.5 to 6.5 $\frac{kWh}{m^2}$ (DME 2003). CPV is also well suited for off-grid application, which addresses electricity demand in remote rural areas.

A case study was chosen were CPV could be applied in the South African context. The Eastern Cape is the focus of the study owing to the high levels of poverty and the low levels of electrification in the province. In 1999 approximately 51% of rural households in South Africa were without electricity. The Eastern Cape in particular, in 2002, 61.8% of rural people had no access to electricity, whereas only 4.8% of urban areas had no access (Prasad 2005).

The case study is situated in the Tyefu irrigation scheme and surrounding rural settlements (Maliti 2010). It was determined that 84 households have no electricity at all. These households meet their energy demands via traditional means. These include paraffin (lighting), car batteries (television), dry cell batteries (radio) and liquefied petroleum gas (fridge) (Purcell 2011).

A hypothetical project, namely the Tyefu electrification project, is examined in this study. The project aims to construct a 30.3kWp CPV system at the Tyefu irrigation scheme. The objective of the project is to alleviate the impoverished community from the burden of having no electricity, and relying on traditional energy sources. Environmental protection is a secondary aim in terms of government policy – the primary aim is to provide electricity to previously disadvantaged communities.

The primary objective of this study was to establish the economic viability from society and private investor's viewpoints. The secondary aim was to establish whether CPV is more cost effective than conventional PV.

2. Study area

The study area consists of the Tyefu irrigation scheme (see Figure 1) and surrounding rural settlements. The coordinates of the Tyefu irrigation scheme offices are 33°10'34.46"S 26°54'53.66"E, with an elevation of 117m above sea level. It is bordered by the Great Fish River. The administrative seat of the Ngqushwa Local Municipality, Peddie is approximately 19km east of the irrigation offices.

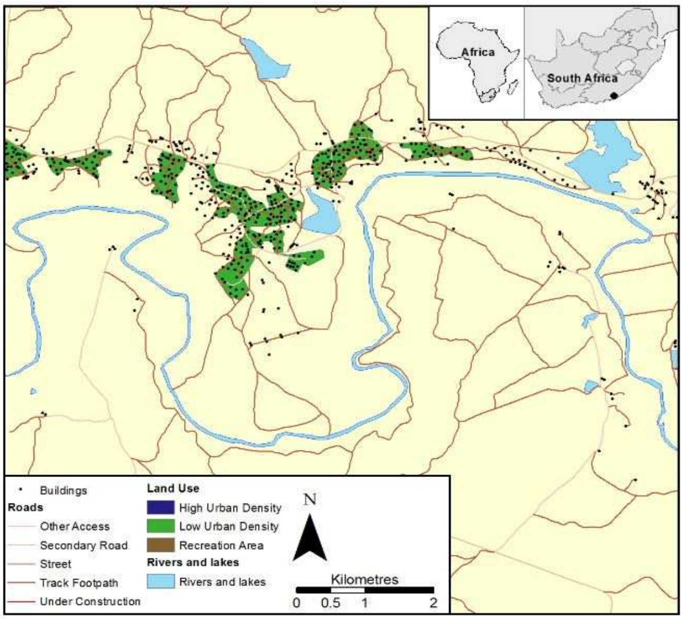

Figure 1. Tyefu irrigation scheme

The annual average level of direct normal irradiance (DNI) for the study area is 5.3 $\frac{kWh}{m^2}$, which is ideal for CPV.

The Tyefu irrigation scheme was developed in 1976 (Bembridge, 1986) to provide water supplies to irrigate the east and west banks of the Great Fish River in the Committees Drift Tyefu area (Bembridge, 2000). Upon the initiation of the irrigation scheme, it was realised that it would not be economically feasible owing to several problems at the time. The Ciskei government, however, proceeded with the scheme due to concerns for poverty alleviation in the area (Bembridge, 2000). The partial closure of the scheme occurred in 1995, with the withdrawal of management by ULIMOCOR (a Ciskei parastatal which was liquidated in May 1997 by the new government's Department of Agriculture), due to major problems that the scheme had encountered.

The local communities around the Tyefu irrigation scheme are poor and most depend on pensions as their main source of income. According to Monde-Gweleta et al. (1997), in 1995, state transfers contributed 54.8% to the household's income of plot holding households at the scheme. The Nqgqushwa Local Municipality area experiences unemployment levels of 78 per cent. Government grants, such as pensions, are the stable source of income for households. Majority of households, 66.8 per cent, in the region earn less than R1500 per month (Ngqushwa Local Municipality, 2011).

3. Concentrator photovoltaics

The sunlight entering a solar cell may be concentrated or non-concentrated. Conventional solar PV systems make use of non-concentrated sunlight, whereas with concentrator applications, mirrors or lenses are used to focus or concentrate sunlight onto photovoltaic material and thus increase the intensity of the light, hence, generating greater electricity.

The optic elements (such as lenses) used to concentrate sunlight onto cells with CPV are more efficient and smaller than conventional PV cells. The optic elements, multiply the sunlight intensity by factors that range from 2 (low concentration) to more than 1000 (high concentration). Figure 2 depicts the principle arrangement of a CPV cell.

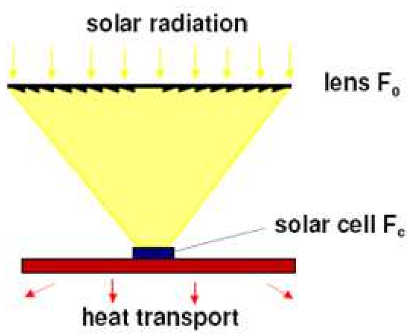

Figure 2. Principle arrangement of a PV concentrator

Sunlight is concentrated by optical devices like lenses (F^o) or mirrors thereby reducing the area of expensive solar cells (F^c) or modules, and furthermore increases their efficiency (Council, 2007).

4. Research Methodology

The research methodology entails the application of two methods, namely a CBA and a CEA. These two research methodologies can be applied for the evaluation of policies and projects which impact on the environment and on communities (Hanley & Spash 1993).

4.1 Cost benefit analysis

CBA is a method of evaluating the costs and benefits of alternative projects. Costs and benefits are measured and then compared to generate various decision making 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 which asks whether the sum of discounted benefits (B) exceeds the sum of discounted costs (C). The NPV can be formally expressed as follows:

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

The decision criterion for acceptance of a project is if it generates a positive NPV. The internal rate of return (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,

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

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:

$$BCR = \frac{\sum_{t=o}^{n} \frac{B_t}{(1+i)^{-t}}}{\sum_{t=o}^{n} \frac{C_t}{(1+i)^{-t}}}$$

If the ratio exceeds unity, then the project may proceed (Hanley and Spash, 1993).

A distinction is also made between social and private CBAs. The former evaluates a project from the perspective of society, whereas the latter evaluates a project from the perspective of a private individual. In a social CBA costs and benefits are valued in terms of their scarcity value. Market prices are adjusted, using techniques such as shadow pricing (conversion factors), in order for the costs and benefits to reflect their social value. In a private CBA market prices are used and no adjustments are made.

4.2 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/output are compared and the project with the lowest ratio is preferred. The cost-effectiveness (CE) ratio for a project can be formally expressed as:

$$CE\ ratio = \frac{Resource\ cost}{Unit\ of\ effectiveness}$$

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 CPV. If the price is low enough, the new strategy can be seen as "cost-effective" (ACP, 2000).

5. Social cost benefit analysis

The project's social perspective is examined via the social CBA. In determining the costs and benefits to consider for analysis, the "with or without" principle is applied. The base case, without CPV is compared to the case with CPV, in order to determine which costs and benefits are relevant for the project. For the social CBA shadow pricing is applied by using conversion factors where needed. The time horizon of the analysis is for 25 years, this is in line with the useful life of the average CPV plant. The discount rate applied is a social discount rate which is determined by the sources of government borrowing. This discount rate was calculated to be 5.97%. The social costs and benefits are now explained below.

5.1 Costs

The base case for the Tyefu electrification project is a case where there is currently no electricity provision in the area. Thus the full costs of the CPV system are considered for analysis. The following costs are taken into account over the lifespan of a CPV system;

investment cost, operating and maintenance, battery replacement, transport and decommissioning costs.

5.1.1 Investment cost

The initial investment cost consists of several key components. The expenditures included are on CPV modules, trackers and the balance of system costs (BOS). The BOS includes an initial set of batteries, expenditure on a regulator and an inverter. The total investment cost is calculated to be R679’379 (for a 30.3kWp plant), this is however the market price. In a social CBA the prices of inputs/outputs need to reflect their relative scarcity. Thus appropriate conversion factors need to be applied. Here, the standard goods conversion factor of 0.88 (0.88=1/1.14) is applied. This eliminates the transfer payment of 14% VAT, and gives a cost that reflects social value. The social investment cost is equal to R595’946.

5.1.2 Operating and maintenance

The operations and maintenance cost is a significant expenditure to consider in the feasibility of the project. Maintenance is an ongoing activity for a CPV plant (Williams 2010). This is due to the system requiring direct normal irradiance (DNI); the cells need to be aligned to the sun at all times. A tracking system serves this need and maintenance is required to keep the trackers in working order.

Water is used to clean the modules, however the usage of water is considered minimal. The fact that the project is located near an irrigation scheme, it can be assumed that the water cost will be zero.

Labour is also required to undertake the maintenance. One skilled labourer and two unskilled labourers for a plant of this size are assumed. In terms of the social costs of labour, the market price of skilled labour is used (Mullins 2007). Whereas with unskilled labour a conversion factor is applied of 0.46 (applied for rural unskilled labour in the Eastern Cape) (Mullins 2007).

Lastly spare parts and replacement equipment will be needed during operations and maintenance. Table 1 below gives the breakdown of the operating and maintenance costs and the appropriate conversion factors applied to arrive at the economic costs.

Table 1. Cost components of operations and maintenance

Operating and maintenance component	Market price (R) (a)	Conversion factor (b)	Economic cost (R) per annum (c)=(a)x(b)
Skilled labour	80’478	1	80’478
Unskilled labour	47’553	0.46	21’875
Equipment and spares	41’968	0.88	36’814
	170’000		139’167

Sources: Pardell 2011, LFS 2007

The total market price for operating and maintenance is R170’000. After applying conversion factors the economic or social cost is equal to R139’167.

5.1.3 Battery replacement cost

An off grid system requires batteries to store energy captured. Batteries need to be replaced, on average, every 4 years. This entails an initial set of 144 batteries, and six periods of replacement over the lifespan of the CPV plant. Battery replacement cost poses a great impact on the outcome of a project and on its economic efficiency due to the size of the cost. The battery replacement cost for an annual replacement is R126'316 in terms of social value.

5.1.4 Transport

The transport cost component is calculated on the hypothetical basis of the capital plant (and all its constituent parts), being shipped from Valencia, Spain to Port Elizabeth, South Africa.

The transport cost total of R15’691 was provided by Safmarine (2011). This is a quote for an 18 ton container, being the smallest container available. The 30.3kWp CPV plant weight is 3.6 ton (Pardell, 2011). The total is composed of a basic ocean freight charge and an array of other charges imposed by both Spanish and South African shipping authorities (Safmarine, 2011).

5.1.5 Decommissioning cost

The decommissioning costs involved are dependent on the plant design and the decommissioning requirements. The costs for decommissioning of the Tyefu CPV plant are the costs for dismantling the tracking structure. This is a small cost and only amounts to R14.57, with a social value of R12.78 after applying the adjustment factor of 0.88 (Mullins et al., 2007).

5.2 Benefits

5.2.1 Primary benefit

The “with or without” principle is applied in identifying the primary benefit. The base case of ‘no electricity’ (without) is compared to the case with CPV. Traditionally rural communities will use traditional means such as paraffin, to meet energy demand. In order to determine the economic benefits, the demand by the 84 households needed to be determined. A sample household is given in Figure 3.

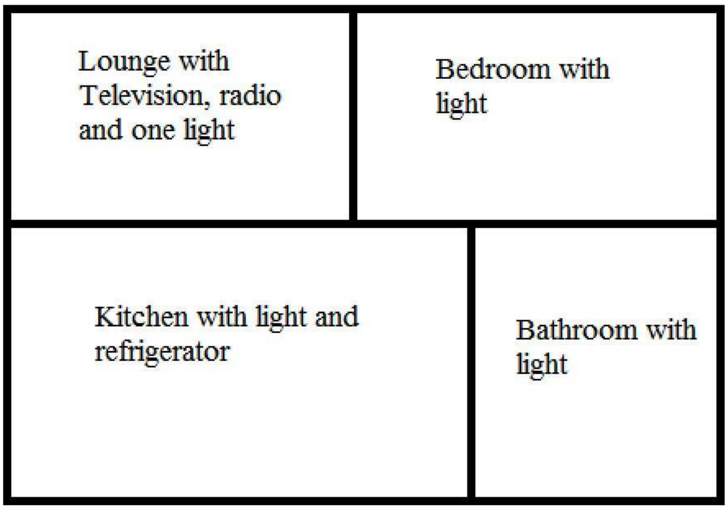

Figure 3. Sample household

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 will require (Purcell 2011):

• 6.39 litres of paraffin (lighting) =R 639.24

• 22 charges for a car battery (TV) = R347.33

• 24 sets (4 batteries per set) of dry cell batteries (Radio) = R360

• 20.11 kilograms of LPG (fridge) = R854.77

Summing these expenditure figures on traditional fuels equals R2’201.34 per household per annum. The social expenditure (after applying the standard goods conversion factor of 0.88) is R1’948. Multiplying this by 84, gives the total economic benefit for the Tyefu community of R163’600 per annum.

5.2.2 Secondary benefit

CPV systems do not emit greenhouse gases. However, the benefit from the decreased emissions by the 84 households is considered minimal, and is thus not included in the analysis.

The income received from recycling the component parts (the system is mainly composed of aluminium, steel and glass) is included. The economic benefit calculated for recycling is R10’601.

Table 2. Income from recycling

Recyclable material	Weight (kg)	Income (R)	Conversion factor	Economic Benefit (R)
Glass	810	178	0.88	156.32
Aluminium	600	6’300	0.88	5’526.32
Steel	2’190	5’606	0.88	4’917.89
Total				10’601

Sources: Reclam, Pardell 2011

5.3 Decision making criteria

Taking the above mentioned costs and benefits into account, the Tyefu Electrification project has a social NPV of R-659'455. The present value of social costs is R2'758'846, and the present value of social benefits is R2'099'390. This results in a BCR of 0.761 and an IRR of 0%.

6 Private cost benefit analysis

The private CBA examines the feasibility of the project from a private investor’s point of view. The private investors are known as independent power producers (IPPs), who finance and construct power plants. A power purchasing agreement (PPA) is set up between the buyer (local municipalities and authorities) and IPP.

The private CBA makes use of market prices and no shadow pricing is applied. The time horizon is 25 years. The discount rate applied is equal to the prime overdraft rate less inflation. This interest rate that reflects the cost of borrowing for firms and is thus used to discount the private cash flows. The costs and benefits for the private CBA are expanded upon below.

6.1 Costs

6.1.1 Investment cost

The investment cost is the same as for the social CBA, and composes of the same components. The total market price is calculated to be R679'379.

6.1.2 Operating and maintenance

The operating and maintenance cost is estimated at R170'000 (Pardell, 2011). The same components as mentioned in Table 1 constituent the operating and maintenance cost, however, the conversion factors are not applied in this case.

6.1.3 Battery replacement cost

The battery replacement cost that is assumed to occur every four years is estimated at R144’000. This cost is also incorporated into the investment cost for the initial set of batteries.

6.1.4 Transport

The transport cost total of R15’691 for the social CBA is also applies to the private CBA.

6.1.5 Decommissioning cost

The costs for decommissioning of the Tyefu CPV plant are the costs for dismantling the tracking structure. This is a small cost and only amounts to R14.57.

6.2 Benefits

The return IPPs earn is known as the renewable feed-in tariff (REFIT). The department of energy announced recently that feed-in tariffs that were proposed previously will now be replaced by a competitive bidding process (SAAEA, 2011). Prices have now been capped per renewable technology, with solar photovoltaic (under which CPV falls) having an upper limit of R2.85/kWh.

The revenue earned is dependent on the output of the system. The expected electricity output is expected to be 30.3MWh per year. Using the current upper limit, 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 income earned at the end of the CPV system's lifecycle, during decommissioning. That is income from the sale of recyclable materials the private investor can sell to recycling plants. The total income from recycling the glass, aluminium and steel is calculated to be R12'085.

6.3 Decision making criteria

The same three decision making criteria that was used for the social CBA was used for the private CBA. The present value of benefits was R1'063'740, the present value of costs was R3'179'242. The NPV from the private investor’s point of view was R-2'155'502. The IRR was 0% and the BCR was 0.335.

7 Cost effectiveness analysis

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. For the Tyefu electrification project CPV and PV are compared. The cost-effectiveness (CE) ratios calculated have identical denominators, in that the annual output for both technologies is identical.

Both CPV and PV systems deliver 30'300kWh per annum. This output is also based according to the demand of the given case study; this variable must thus be kept unchanged when comparing the two technologies. The same discount rate applied in the private CBA, of 6.42%, is used.

Table 3. Summary results of CEA

	PV	CPV
NPV of costs	R3'295'805	R3'179'242
NPV /annum	R126'762	R122'279
CE ratio	R4.18	R4.04

Source: Pardell (2011)

The table shows that CPV has the lower CE ratio of R4.04, and is thus the preferred alternative.

8. Conclusions and Recommendations

8.1 Concluding remarks

The three CBA decision making criteria, namely the NPV, IRR and BCR were applied in order to determine the social and private desirability of the Tyefu electrification project. In addition a CEA was carried out in order to determine the cost effectiveness of CPV in comparison to PV.

The project was found to be socially undesirable in terms of all three decision making criteria. The project will therefore not be feasible for government to undertake, and will not be an economic allocation of resources.

A private CBA was carried out after the social one. This was done to determine the financial flows of the project, and to establish its feasibility. The project was found to not be a profitable investment. This was mainly due to the size of the Tyefu CPV system.

Hereafter, a CEA was carried out to compare CPV to traditional PV. The results showed that CPV had a lower CE ratio and was thus more cost effective than PV.

Both CBA's show that the Tyefu electrification project is not feasible from both society and investors perspectives.

5.2 Recommendations

It is recommended that further studies be carried out for similar solar projects of this kind. These results are subject to qualifications. Firstly the project size is relatively small and only considers the demand for 84 households. Secondly, the environmental costs and benefits were mentioned but not measured.

The project could become more viable if the CPV system produced more output. The annual output was not large enough to generate enough income to overcome the large costs of maintenance and battery replacement.

CPV technology would be socially viable if the system did not have to replace batteries every four years. This would be achieved by having the system connected to the grid. Operations and maintenance costs are also a major cost that influences the decision to accept or not.

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