A cost-benefit analysis of concentrator photovoltaic technology use in South Africa: A case study

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Abstract

The South African Government currently faces the dual problems of climate change mitigation and the rollout of electricity provision to rural, previously disadvantaged communities. This paper investigates the economic efficiency of the implementation of concentrator photovoltaic (CPV) technology in the Tyefu area in the Eastern Cape, South Africa, as a means of addressing these problems. Two cost-benefit analyses (CBA) are carried out in the study, namely a private CBA and a social CBA. The private CBA investigates the desirability of the CPV project from a private energy investor's perspective, whilst the social CBA investigates the desirability of the CPV project from society's perspective. The social CBA found that the project was socially viable and was, thus, an efficient allocation of government resources. The private CBA, on the other hand, found that investing in a CPV project was not financially viable for a private investor. With respect to the incentive scheme currently offered to private energy investors, it is recommended that the maximum bidding price of R2.85/kWh be increased. A sensitivity analysis of the bidding price showed that an increase of 300% is required to attract private investors into electricity generation projects.

Keywords: Cost-benefit analysis, concentrator photovoltaic technology, social discount rate

1. Introduction

South Africa relies heavily on fossil fuels, particularly coal, to generate electricity (Department of Minerals and Energy, 2003). The use of fossil fuels, however, contributes to climate change, as it produces greenhouse gases (GHGs). Internationally, South Africa is the 31th highest emitter of CO_2 emissions with 9.2 metric tons per capita, whereas it is ranked 20th highest emitter of CO_2 emissions with 1.59 metric tons per GDP (World Bank, 2010). 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 mostly rural, 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 is a form of active[1] solar-based renewable technologies that absorb energy from the sun into solar PV panels consisting of cells. The sunlight entering the cell is concentrated[2] through the use of mirrors or lenses that focus or concentrate sunlight onto PV material. The concentration of sunlight increases the intensity of the light, which allows the generation of more electricity. 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. The optical elements (such as lenses) multiply the sunlight intensity by factors that range from 2 (low concentration) to more than 1000 (high concentration). Figure 1 depicts the principle arrangement of a CPV concentrator.
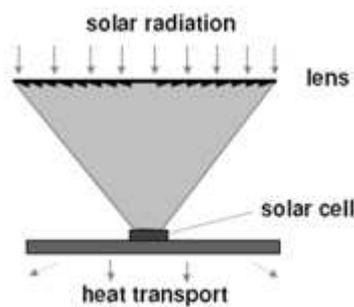
Figure 1: Principle arrangement of a CPV concentrator

Sunlight is concentrated by optical devices like lenses or mirrors thereby reducing the area of expensive solar cells and 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 in turn significantly lower the costs of photovoltaic 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 is the most common application and 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).

CPV is a technology that operates well in regions with high solar radiation, utilising direct normal irradiance. As such, South Africa is particularly well suited for this technology, with average solar radiation levels ranging from 4.5 to 6.5kWh/m^2. CPV is also well suited for off-grid application, which addresses electricity demand in remote rural areas.

There is, however, a paucity of published studies that establish the economic rationale for the use of solar energy in South Africa. This study aims to fill this gap. To the authors' knowledge, this is the first formal attempt in South Africa to establish the economic efficiency of the use of CPV. The approach employed to achieve this aim is the cost benefit analysis (CBA) method. Two types of CBA are performed, namely a private CBA and a social CBA. The private CBA evaluates the CPV project from a private investor's perspective and the social CBA evaluates the CPV project from society's point of view. In terms of the social CBA, the current means of providing electricity can be viewed as the 'without scenario', while the CPV project is the 'with scenario'. The net benefit arising from the CPV project will simply be the difference between the 'with' and 'without' scenarios. In order to estimate the net benefit, an attempt is made to identify and estimate (where possible) the social benefits and social costs that will occur upon project execution. With respect to the private CBA, the private benefits of the CPV project are simply compared to the private costs.

The study area chosen for the implementation of the CPV project is the Tyefu rural[3] settlement located in the Eastern Cape, South Africa. 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). 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). 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. Tyefu was deemed ideal to serve as a case study due to four characteristics. First, Tyefu is a remote rural settlement at the end of the national grid. Second, the community is very poor and previously disadvantaged. Third, many households are without Eskom generated electricity. Last, the study area is located in an area with irradiance levels suitable for CPV. CPV technology requires direct normal irradiance (DNI) from the sun to generate electricity. The Tyefu area experiences annual average DNI levels of 5.27kWh/m^2 which are ideal for CPV systems (National Renewable Energy Laboratory, 2011).

2. The CPV project

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 CPV project, is based. Traditionally, unelectrified rural, households, such as those found in Tyefu, have obtained their energy from several sources, namely paraffin, candles, liquefied petroleum gas (LPG), dry-cell batteries, car batteries, wood, and diesel and petrol generators (Aitken, 2007). 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 results and personal correspondence (Purcell, 2011). Figure 2 provides the basic floor plan of a sample household for which a CPV system can provide electricity.

Figure 2 depicts a household which uses four fluorescent lamps, a television set, a radio and refrigerator. In order to provide an equivalent amount of energy[4] to light four rooms, run a television set, radio and refrigerator for one year, the typ-
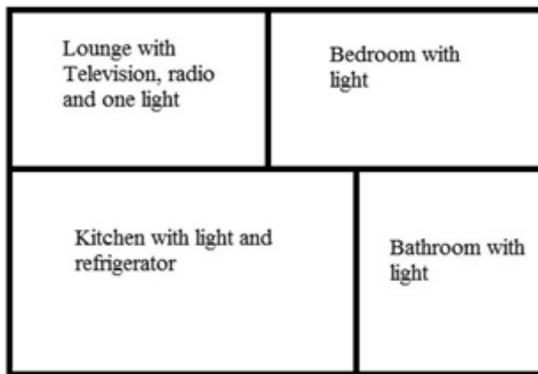
Figure 2: Sample household

ical Tyefu household requires:
- 6.39 litres of paraffin (lighting) at a cost of R639.24 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).

In order to meet the electricity needs of the sample households identified, a CPV system will be installed and operated ('the CPV project') with an electricity generating capacity of 30kWp and an annual output of 30.3MWh per annum. The CPV modules that will be used are mounted on a dual-axis system in order to track the sun's movement. A battery bank will be used to store the energy produced for use at non-generating hours.

Either Eskom or independent power producers (IPPs) could implement the CPV project in the Tyefu area. 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 (Norton Rose, 2011). 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 (Pardell, 2011). The installation of the CPV system could be carried out by a services engineering and management company regardless of whether Eskom or an IPP were to undertake the project. Installation of the 30kWp system would take approximately 2 months. 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.

3. Cost benefit analysis

Cost benefit analysis (CBA) is a standard technique used to assess the desirability of an investment project (Watkins, 2010). More specifically, the costs and benefits of a project are determined and compared. The measured costs and benefits are weighed up against each other to establish criteria for decision-making. Normally, one or more of the following three decision-making criteria are used, namely the net present value (NPV), the internal rate of return (IRR) and the discounted benefit cost ratio (BCR) (Hanley and Spash, 1993). The NPV determines whether the sum of discounted benefits (B) exceeds the sum of discounted costs (C). The NPV can be formally expressed as follows:

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

where:
NPV = net present value B_t = benefit in year t
C_t = cost in year t
i = the discount rate
n = length of the project

A project is accepted if it generates a positive NPV. The IRR is the rate of interest that will produce a NPV of zero (if this interest rate is used as the discount rate). More formally:

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} = 0 \quad (2)$$

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 (Hanley and Spash, 1993). More formally, the BCR can be expressed as follows:

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \quad (3)$$

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

There are four standard elements to CBA: time considerations, costs, benefits, and the discount rate. All of these are discussed below for the private CBA and the social CBA, respectively.

3.1 Private CBA

The private CBA employs costs and benefits valued at market prices (i.e. purely financial flows), and omit any potential effects the project may have on society.

3.1.1 Time considerations

All the estimated private cost and private benefit flows used in this analysis are captured in per annum periods and expressed at 2010 price levels.

Table 1: Derivation of the system cost

Cost component	Euro/Wp (a)	Rand/Euro (b)	Rand/Wp (c) = (a) x (b)	System size (Wp) (d)	Local cost (R) (e) = (c) x (d)
System	0.88	9.71	8.58	30 000	257 305.54

The project period or time horizon of the project was set at 25 years.

3.1.2 The private costs of the CPV project
Investment costs
The investment cost comprises initial capital costs on the system (500 times concentration CPV modules, trackers and inverters), the regulator, initial battery bank, transportation (foreign and local), installation and training. Of all the capital equipment, only the system is imported– the regulator and battery bank are acquired locally. The derivation of the system cost is shown in Table 1.

Local transport consists of a fee of R8 950 per container (one container is used) and a fuel surcharge of 5.3 percent. 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 (Emery, 2011). In addition to these costs, costs are also incurred for the installation of the system and the training of maintenance staff. Table 2 below gives the breakdown of the investment cost component.

Table 2: Private investment cost derivation
Source: Emery (2011); Pardell (2011)

Cost component	Private cost (R)
System	257 305.54
Regulator	40 000
Batteries (96 batteries)	96 000
Insurance and freight	206 915.57
Local transport	9 424.35
Installation	217 675.24
Training	10 000
Total	**837 320.69**

Operating and maintenance costs
Annual operating and maintenance costs consist of expenditures on labour (two unskilled labourers for routine tasks and one skilled labourer to manage the plant and to perform more advanced tasks), materials (spare parts and lubricants) and water (water cost is assumed to be zero since the amount used is considered negligible). In addition to the annual operating and maintenance costs, every four years the cost to replace the battery bank is added to the annual figure. The operating and maintenance costs (with battery cost) are displayed in Table 3.

Table 3: Cost components of operating and maintenance with battery cost
Source: Pardell (2011); Statistics South Africa (2007)

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[5]
Total	266 000

Decommissioning costs
Lastly, decommissioning costs (occurring in the final year) comprise of costs to dismantle the CPV plant. This cost equals R14 569.96 (Pardell, 2011).

3.1.3 The private benefits of the CPV project
The private benefits are the revenue earned by the private investor who initiates 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 (Norton Rose, 2011). 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 (Norton Rose, 2011), the expected revenue from the sale of electricity is R86 355 per annum.

Income from recycling the plant's components during decommissioning, and the recycling of the batteries every four years (Table 4), is also included in the private analysis. This amounted to R12 084.60.

Table 4: A breakdown of the income from recycling the CPV plant
Source: Goosen (2011)

Component	Weight (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

3.1.4 The private discount rate
The private discount rate was estimated as the difference between the prime lending rate and the inflation rate. Table 5 shows the data used for this calculation.

Table 5: Data for the derivation of private discount rate
Source: SARB (2010)

Year	Prime overdraft rate %	Inflation rate %
2006	11.17	3.1
2007	13.17	5
2008	15.13	11.5
2009	11.71	6.4
2010	9.83	2.9

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

3.2 Social CBA

The costs and benefits used in the private CBA are amended (via shadow pricing) for the purposes of the social CBA to reflect their underlying opportunity costs. Externalities (secondary effects) are identified and classified under the appropriate cost or benefit category.

3.2.1 Time considerations
All estimated social cost and social benefit flows derived in this analysis are captured in per annum periods and expressed at 2010 price levels. A distributional weighting of one was used for all cross-sectional costs and benefits over the full project period. This weighting assumes that a Rand benefit is worth the same to all members of the population affected by the project. The project period for the project was set at 25 years.

3.2.2 The social costs of the CPV project
Investment costs
As mentioned before, of all the capital equipment, only the system is imported. The social cost for the imported system is the sum of its fob price plus the c.i.f. (European Union, 2008). The social cost of the system was calculated to be R290 222.90 (i.e. R257 305.54 + R32 917.36). The social cost of the system is considerably lower than its private cost since taxes (i.e. customs duties and customs VAT amounting to R173 998.21) are excluded from the former.

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 6.

The components of the total economic investment cost are shown in Table 7.

Operating and maintenance costs
Of all the operating and maintenance costs identified in section 3.1.2, the following ones require transformation into economic costs: salaries and wages, battery replacement, spare parts and lubri-

cants (as mentioned before, water costs are assumed to be zero). This is carried out by applying the relevant conversion factors as recommended by Mullins et al. (2007).

Table 6: Derivation of shadow prices for investment cost components

Cost component[6]	Market price (R)	Conversion factor	Economic cost (R)
Regulator	40 000	0.88	35 087.72
Batteries[7] [7]	96 000	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	0.88	8 771.93
Total	373 099.59	0.88	327280.34

Table 7: 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

Table 8: Economic cost derivation of operating and maintenance with battery cost
Source: Pardell (2011); Statistics South Africa (2007). Mullins et al. (2007)

Operating and maintenance component	Market price (R) p.a.	Conversion factor	Economic cost (R) p.a.
One skilled labourer	80 478.22	1	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	0.88	84 210.53
Total	266 000		223 377.60

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. The economic decommissioning cost amounts to R12 780.67 (R14 569.96 0.88).

Secondary (externality) costs
A secondary cost is that the landscape may be negatively affected, aesthetically and in terms of lost area available for other uses such as agriculture. CPV, however, 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, 2011b).

3.2.3 The social benefits of the CPV project
Primary benefits
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. These avoided costs are the economic benefits of CPV in the study.[8] The savings of recurring energy costs relative to the existing situation for 84 households amounted to R201 137.04 per annum (Purcell, 2011). The disaggregated cost savings are shown in Table 9.

Table 9: Disaggregated cost savings
Source: Purcell (2011)

Component	Cost per household p.a. (R) (a)	No. of households (b)	Total (R) (c) = (a) x (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

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

Income from recycling the plant's components during decommissioning, and the recycling of the batteries every four years, is also considered in the social analysis. 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 10 shows the income from recycling.

Secondary benefits
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).

3.2.4 The social discount rate
The social discount rate used is a composite rate made up of the social opportunity cost of capital (SOCC) and the social time preference rate of consumption (STPR).

The composite social discount rate can be estimated as follows:

$$i = (1 - f)t[(1 - s)(x_1 - p) + (s)(x_2 - p)] + (1 - f)(1 - t)(x_3 - p) + f(x_4 - p) \qquad (4)$$

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 ncome 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;
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 these mentioned variables for the period 2006 to 2010. Table 11 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 12 shows the calculation of weights t and $1 - t$ and Table 13 shows the calculation of weights s and $1 - s$.

Using the above equation and the data provided in Tables 11, 12 and 13, the real social discount rate was estimated at 5.97 percent per annum.

Table 10: Income from recycling the CPV plant and batteries

Component	Weight (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	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

Table 11: Cost of government borrowing, cost of household consumption borrowing, the return on savings and the annual inflation rate (2006-2010)
Source: SARB (2010)

Year	Cost of government borrowing			Cost of household consumption borrowing			Return on savings			
	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
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

Table 12: The calculation of discount rate weights *t* and *1 – t*
Source: SARB (2010)

Year	Government borrowing requirement R millions (a)	Government revenue R millions (b)	Total R millions (c) = (a) + (b)	Borrowing proportion (a)/(b) (1 – t)	Tax revenue proportion (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

Table 13: The calculation of discount rate weights *s* and 1 – *s*
Source: SARB (2010)

Year	Final consump-tionexpenditure R millions (a)	Gross savings R millions (b)	Gross national disposable income (c) = (a) + (b)	Final consumption expenditure proportion (a)/(b) (1 – s)	Gross savings proportion (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

4. Summary results of applying the decision-making criteria
4.1 Private CBA
The mentioned costs and benefits along with the private discount rate were used to estimate the NPV, IRR and BCR of the private project. These results are summarised in Table 14.

Table 14: 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 private CBA shows unfavourable results – the NPV is R-2 046 629.01, the IRR is undefined (this is due to no sign change being present in the cost benefit profile), and BCR is less than unity (0.365).

4.2 Social CBA
The above mentioned costs and benefits along with the social discount rate were used to estimate the NPV, IRR and BCR of the social project. These results are summarised in Table 15.

Table 15: 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 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.

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

5.1.1 The private 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 in Table 16.

Table 16: 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.

5.1.2 The bidding price
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 (Norton Rose, 2011). The price was increased by 200 percent, 250 percent, and 300 percent. The results of the sensitivity analyses are shown in Table 17.

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

5.2 Social CBA
A sensitivity analysis is applied to the social CBA to test the results by altering the 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 in Table 18.

Table 18: Sensitivity analysis – discount rate

CBA decision-making criteria[9]		
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.

Table 17: Sensitivity analysis – bidding price change

		CBA decision-making criteria		
Bidding price (per kWh)	Revenue (pa) (R)	NPV (R)	IRR(%)	BCR
R5.70 (200%)	172710	-913 476.78	Undefined	0.726
R7.13 (250%)	215887.5	-346 900.66	1%	0.896
R8.55 (300%)	259065	219 675.45	9%	1.066

6. Conclusion and recommendations

The purpose of this study was to evaluate the economic feasibility of a concentrator photovoltaic project in a non-electrified, rural, previously disadvantaged community. 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. Two cost benefit analyses (CBAs) were carried out: a private CBA to investigate the project's feasibility from a private energy investor's point of view, and a social CBA to investigate the project's desirability from society's perspective.

The main results were favourable in terms of the social CBA, but unfavourable for the private CBA. More specifically, the social CBA yielded 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, whereas the private CBA yielded a NPV of R-2 046 629.01 and a BCR of 0.365 (the IRR could not be calculated as there was no sign change in the cost benefit profile – all net benefits were negative).

It can thus be deduced that CPV rollout appears to be economically efficient on a small scale according to the social CBA, but not according to the private CBA. The benefit (income received per kWh) in the private CBA is too small to outweigh the costs of implementing and running a CPV plant in Tyefu. Currently the maximum revenue investors can earn from CPV is R2.85/kWh (Norton Rose, 2011). For a small plant of Tyefu's size, this amount is not high enough to attract private energy investors into undertaking a project of this kind. A sensitivity analysis showed that the current upper limit must be increased by up to 300% to make a project of this magnitude financially viable.

Notes

1. Passive solar energy refers to the design of buildings for harnessing the sun's energy.
2. Conventional solar PV systems make use of non-concentrated sunlight.
3. An anonymous referee made the valid point that normal PV prices have fallen since 2010. Therefore small scale CPV which is more maintenance intensive, may be difficult to justify in remote rural areas.
4. These costs were calculated using an energy conversion table where the useful energy is determined per traditional fuel (Purcell, 2011).
5. The battery cost is only incurred every four years.
6. All cost components relate to a system size of 30 000 Wp.
7. 96 batteries are required for electricity storage.
8. An anonymous referee made the valid point that if electricity was generated for income generation (productive use), then both the social and private perspectives would change in a positive direction.
9. 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%.

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