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. A cost-benefit analysis (CBA), both from a social and a private perspective, is carried out in the study. The CBA from a private perspective investigates the desirability of the CPV project from a private energy investor's point of view, whilst the CBA from a social perspective investigates the desirability of the CPV project from society's point of view. The CBA from a social perspective found that the project was socially viable and was, thus, an efficient allocation of government resources. The CBA from a private perspective, on the other hand, found that investing in a CPV project was not financially viable for a private investor. It is recommended that the government consider CPV as an alternative to grid-connected electricity provision to rural, previously disadvantaged communities.

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 (DME), 2003). The use of fossil fuels, however, contributes to climate change, as it produces greenhouse gases (GHGs). 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

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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.

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. As such, South Africa is particularly well suited for this technology, with average solar radiation levels ranging from 4.5 to 6.5 kWh/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. The CBA is carried out from two perspectives, a social one and a private one. The CBA from a private perspective evaluates the CPV project from a private investor's

[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.

point of view and the CBA from a social perspective evaluates the CPV project from society's point of view. In terms of the CBA from a social perspective, 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 execution of the project. With respect to the CBA from a private perspective, 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 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 5.27 kWh/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[3] to light four rooms, run a television set, radio and refrigerator for one year, the typical 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 (Aitken, 2007; Purcell, 2011).

In order to meet the electricity needs of the sample households identified above, 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. More specifically, the costs and benefits of a project are determined and compared (European Union, 2008). The measured costs and benefits are weighed up against each other to establish criteria for

[3] These costs were calculated using an energy conversion table where the useful energy is determined per traditional fuel (Purcell, 2011).

decision-making. Normally, one or both of the following two decision-making criteria are used, namely the net present value (NPV) and the discounted benefit cost ratio (BCR) (European Union, 2008). 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:

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

where:
NVP = net present value
B_t = benefit in year t
C_t = cost in year t
i = the discount rate
n = length of the project (European Union, 2008).
A project is accepted if it generates a positive NPV.

The BCR is a different way of expressing the NPV (European Union, 2008). More formally, the BCR can be expressed as follows:

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

If the BCR exceeds unity, then the project may proceed (European Union, 2008).

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

3.1 CBA from a private perspective

The CBA from a private perspective 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. 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 (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 and costs R40 000 and R96 000, respectively. The derivation of the system cost is carried out according to the European Union's CBA guidelines (European Union, 2008) – the private cost of the imported system is the sum of its free-on-board (fob) price, cost-insurance-freight (c.i.f.) and taxes, such as customs duties and value-added tax (VAT). The private cost of the system was calculated to be R464 221. This amount included the fob price, R257 305.54, the c.i.f., R32 917.36, and taxes, namely customs duties (R80 306.85) and customs VAT (R93 691.36) among other charges imposed by both local and foreign ports (Emery, 2011)

The local transport cost consists of a fee of R8950 per container (one container is used) and a fuel surcharge of 5.3 percent. In addition to these costs, costs are also incurred for the instillation of the system and the training of maintenance staff. Table 1 shows the breakdown of the investment cost component.

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 are displayed in Table 2.

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 (Table 3), and the recycling of the batteries every four years (R55 473.60), is also included in the private analysis. This amounted to R12 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 4 below shows the data used for this calculation.

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

3.2 CBA from a social perspective

The costs and benefits used in the CBA from a private perspective are amended (via shadow pricing) for the purposes of the CBA from a social perspective 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. The project period 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 5.

The components of the total economic investment cost are shown in Table 6.

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 lubricants (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) (see Table 7).

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 x 0.88).

Secondary (externality) costs

Two secondary costs are relevant: one, the landscape may be aesthetically negatively affected, and two, ground area available for other uses, such as agriculture, may be lost. As far as the first cost is concerned, the visual impact on the site location is deemed to be minimal (Daido, 2011b). In terms of the second cost, the ground beneath the CPV panel receives enough sunlight so that it may be used for agricultural purposes.

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. 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, before applying the standard conversion factor, are shown in Table 8 below.

The total cost savings amount was converted into an economic benefit by applying the standard conversion factor (R229 296.20 x 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 9 shows the income from recycling.

Secondary benefits

Two secondary benefits are applicable: one, CPV systems do not emit any GHGs during power generation, and two, health costs associated with traditional energy creating methods, such as smoke inhalation from wood fires, are averted. The first benefit is insignificant, given the size of the study area, and is thus not included in the analysis (SolFocus, 2011b). The second benefit is assumed to be negligible since a lot of cooking happens outdoors and is thus also not included.

3.2.4 The social discount rate

The social discount rate used in this study is the social time preference rate (STPR)[4]. This rate is based on the long term growth rate in the economy and takes into account preferences for benefits over time (European Union, 2008). The STPR, r, can be defined as follows:

$$r = eg + p \tag{3}$$

where:

e = the elasticity of marginal social welfare with respect to public expenditure

g = the growth rate of public expenditure

p = the pure time preference rate (European Union, 2008).

As per the European Union's (2008) CBA guidelines, social and individual preferences affect the marginal utility variable, e whereas life expectancy and individual characteristics affect the time preference variable, p. Mortality rate statistics for the country in question are commonly used as a proxy for p. The

[4] An anonymous referee argued that the use of a weighted average discount rate is inadequate.

annual real per capita GDP growth rate is used as a proxy for g. It is recommended by Brent (1990) that the elasticity of marginal social welfare[5] is set equal to 0.5.

Data was collected for g and p in Equation (3) for the period 2006 to 2010 Table 10 shows the annual real per capita GDP growth rate (g) and the annual death rate (p). Using Equation (3) the elasticity of marginal social welfare (e) equal to 0.5, and the data in Table 10, the STPR for the period 2006 to 2010 was estimated at 2.91%

4 Summary results of applying the decision-making criteria

4.1 CBA from a private perspective

The above mentioned private costs (Section 3.1.2) and private benefits (Section 3.1.3) along with the private discount rate (Section 3.1.4) were used to estimate the NPV and BCR. These results are summarised in Table 11.

The CBA from a private perspective shows unfavourable results with the NPV at R-2 046 629.01, and the BCR less than unity (0.386).

4.2 CBA from a social perspective

The above mentioned social costs (Section 3.2.2) and social benefits along (Section 3.2.3) with the social discount rate (Section 3.2.4) were used to estimate the NPV and BCR. Since income distribution is a concern (responsibility) in the case of this project, unit equal weights (i.e. efficiency-only weights) should not be employed for the beneficiaries of the project. Thus, a distribution weight is used to conduct the social cost benefit analysis. According to Squire and Van der Tak (1975), the following formula for the weight, a_i, attached to the benefits and costs for any group i can be used:

$$a_i = \left(\frac{\bar{Y}}{Y_i}\right)^e \tag{5}$$

where:
$\bar{Y}$ = the average income
Y_i = the income level of group

[5] Alternatively, the prgressiveness of the country in question's tax structure can be used at a proxy for the elasticity of marginal social welfare. the formula to estimate the extent of the progressiveness can be formally expressed as follows:

$$e = Log(1-t)/Log(1-T/Y) \tag{4}$$

where:
t = the marignal rate of income tax
T = the total income tax liability
Y = the total taxable income (European Union, 2008).

e = income inequality parameter

Brent (1990) recommends the use of $e = \frac{1}{2}$ in Equation (5). For a country like South Africa where the poor (the lowest quintile) earn 15.3% of the income of the middle (average) quintile, $\left(\frac{\bar{Y}}{Y_i}\right) = 6.5$ and the Equation (5) would give the weight[6] for the poor equal to $(6.5)^{0.5} = 2.55$, close to 3. A distributional weight of 3, as recommended by Brent (2006), was thus attached to the benefits received by the Tyefu community, whilst a unit weight was attached to the costs of the project. In other words, during the estimation of Equations (1) and (2), the annual benefit flows were multiplied by a value of 3, whereas the annual cost flows were multiplied by a value of 1. These results are summarised in Table 12.

The CBA from a social perspective yielded positive results with a NPV of R8 201 282.65 and a BCR of 3.321.

5 Sensitivity analysis

5.1 CBA from a private perspective

5.1.1 The private discount rate

The derived private discount rate of 6.42% was revised upwards and downwards by 2 percentage points and 4 percentage points, respectively. The results are shown below in Table 13.

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

5.2 CBA from a social perspective

5.2.1 The social discount rate

The derived social discount rate of 2.91% was revised upwards by 1% points and downwards by 1% point. The revision was based on the recommendation by Brent (1990) that values of e between 0 and 1 be employed as part of the sensitivity analysis. Seeing that $e = 0.5$ was used to derive the STPR, the lower limit and the upper limit of the recommended e was employed. Thus, a value of $e = 0$ produced a social discount rate equal to 1.91%, whereas a value of $e = 1$ produced a rate equal to 3.91%. The results of varying the social discount rate are shown below in Table 14.

In terms of both the NPV and BCR, the project remains socially desirable for all changes of the discount rate.

5.2.2 Distributional weighting

As part of the sensitivity analysis, unit equal weights (i.e. efficiency-only weights) were employed for the beneficiaries of the project. Thus, a distributional weight

[6] We would like to thank an anonymous ERSA referee for pointing this out.

of one (unity) was attached to both the benefits received by the Tyefu community, and the costs of the project. The results are shown in Table 15.

A distributional weighting of this kind reduces the social desirability of the project greatly.

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. A cost benefit analysis (CBA) was carried out from two perspectives: a private one (to investigate the project's feasibility from a private energy investor's point of view), and a social one (to investigate the project's desirability from society's point of view).

The main results were favourable in terms of the CBA from a social perspective, but unfavourable for the CBA from a private perspective. More specifically, the CBA from a social perspective yielded a NPV of R8 201 282.65, and a BCR of 3.321, whereas the CBA from a private perspective yielded a NPV of R-2 046 629.01 and a BCR of 0.386. The results of the CBA from a social perspective do not take into account the environmental advantages associated with the use of CPV, and as such the social benefit may be a slight underestimate. These advantages (or external benefits) include, but are not limited to, averted health costs and the fact that no GHGs are emitted during CPV power generation.

It can thus be deduced that CPV rollout appears to be economically efficient on a small scale according to the CBA from a social perspective, but not according to the CBA from a private perspective. The benefit (income received per kWh) in the CBA from a private perspective 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).

Owing to CPV's social desirability, it is recommended that government consider CPV as an alternative to grid-connected electricity provision to rural, previously disadvantaged communities.

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Table 1: Private Investment Cost Derivation

Cost component	Private cost (R)
System cost = fob+c.i.f.+taxes	464 221
Regulator	40 000
Batteries (96 batteries)	96 000
Local transport	9 424.35
Installation	217 675.24
Training	10 000
Total	**837 320.69**

Source: Emery (2011); Pardell (2011)

Table 2: 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
Total	**266 000**

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

Table 3: A Breakdown of the Income from Recycling the CPV Plant

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**

Source: Goosen (2011)

Table 4: Data for the Derivation of Private Discount Rate

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

Source: SARB (2010)

Table 5: Derivation of Shadow Prices for Locally-sourced Investment Components

Cost component[i]	Market price (R)	Conversion factor	Economic cost (R)
Regulator	40 000	0.88	35 087.72
Batteries[ii]	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 6: Total Economic Investment Cost

Economic cost component	R
System cost = fob+c.i.f	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 7: 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	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**

Source: Pardell (2011); Statistics South Africa (2007). Mullins *et al.* (2007)

Table 8: Disaggregated Cost Savings

Component	Cost per household per annum (R) $(\boldsymbol{a})$	Number of households $(\boldsymbol{b})$	Total (R) $(\boldsymbol{c}) = (\boldsymbol{a}) \times (\boldsymbol{b})$
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: Aitken (2007); Purcell (2011)

Table 9: 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 10: Annual real per capita GDP growth rate, Death rate (2006-2010)

Year	Annual real per capita GDP growth rate (g)	Death rate (p)
2006	4.20	2.20
2007	4.30	2.25
2008	2.40	1.69
2009	-2.70	1.70
2010	1.80	1.69
Average (05'-09')	**2.00**	**1.91**

Source: SARB (2010), National Treasury and SARS (2010), CIA World Fact Book (2012)

Table 11: Summary Results of CBA Decision Criteria (private perspective)

CBA criteria (at private discount rate of 6.42%)	
NPV (R)	**BCR**
-2 046 629.01	0.386

Table 12: Summary Results of CBA Decision Criteria (social perspective)

CBA criteria (at social discount rate of 6.15%)	
NPV (R)	**BCR**
8 201 282.65	3.321

Table 13: Sensitivity Analysis - Discount Rate (private perspective)

	CBA Decision- Making Criteria	
Discount rate (%)	**NPV (R)**	**BCR**
2.42 (-4% points)	- 2 640 006.58	0.422
4.42(-2% points)	- 2 297 030.96	0.404
6.42	-2 046 629.01	0.386
8.42(+2% points)	- 1 860 022.39	0.369
10.42(+4% points)	- 1 718 182.17	0.353

Table 14: Sensitivity Analysis - Discount Rate (social perspective)

	CBA Decision-Making Criteria[iii]	
Discount rate	**NPV (R)**	**BCR**
1.91% (-1% points)	7 326 302.24	3.261
2.91%	8 201 282.65	3.321
3.91%(+1% points)	9 233 066.17	3.380

Table 15: Sensitivity Analysis – Distributional weighting

	NPV(R)	**BCR**
Unit weighting (efficiency-only weighting)	378 018.73	1.107
Distributional weighting	8 201 282.65	3.321

Figure 1: Principle Arrangement of a CPV Concentrator

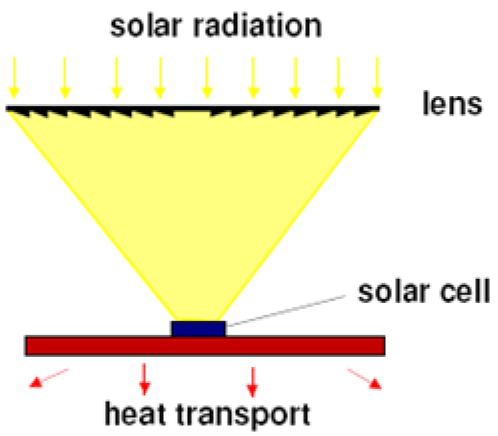
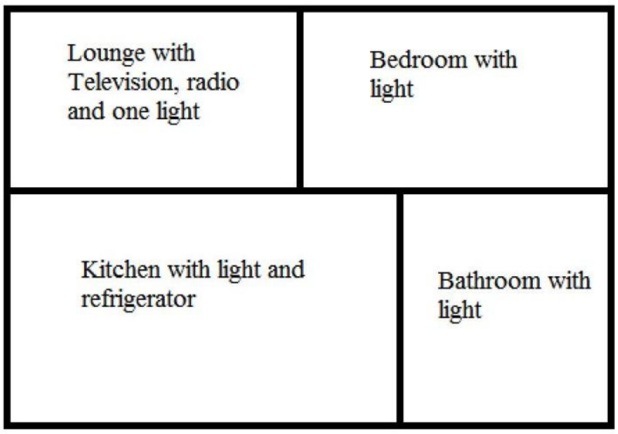


Figure 2: Sample Household



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