Technical and Economical Prefeasibility Study of a Solar Water Heating (SWH) System in an Apartment Building in Cape Town

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1 Introduction

The centrally generated electrical power in South Africa consists of 92.6% coal-fuelled power—the aging coal-fuelled South African plants have the lowest operating efficiency in the world (de Groot and Sebitosi 2013). Moreover, water heating represents up to 48% of total electricity consumption in South African homes (Geldenhuys 1998). Although the country has a fairly high annual average solar irradiation levels of 5.4 kWh/m^2/day measured on a horizontal plane that could make solar energy recovery a favorable alternative (Boxwell 2015), only about 1% of households utilize solar water heaters (DME 2003). Rising electricity rates, capital investments in electricity production, and distribution, as well as needs to reduce CO_2 emissions, have all led the government to start promoting alternative, renewable energy solutions to meet growing energy demands (Donev et al. 2012).

Promoting solar water heating (SWH) has been at the forefront of this initiative, with significant grants being offered by Eskom, South Africa's public electricity utility. Between the years 2008 and 2011 alone, Eskom has incentivized 156,000 installations with its Solar Water Heating Rebate Programme and has partnered with the Department of Energy to reduce the demand on the public grid by 2300 GWh through the use of SWH (ESKOM 2012). The legislative capital of the country, Cape Town, has launched its own initiative in the form of the Residential

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Solar Water Heater Programme, which has encouraged residents through financial services and technical support to “invest to save” in SWH (City of Cape Town 2011). With temperatures in Cape Town ranging from 2 °C to 37 °C, an annual average of 17 °C (The Weather Channel LLC 2014), and an average of 2993 h of sunshine per year (Climatemps 2014), SWH is an attractive clean energy alternative to electric water heaters. According to a recent survey conducted by the City of Cape Town, nearly 70% of residents want a solar water heater (with energy cost savings cited as the primary reason), and half of the respondents replied that it is likely they would install one within the next 3 years (City of Cape Town and Du Toit 2013).

Given that energy cost savings are an important motivating factor for consumers who plan to install a solar water heating system (SWHS), economic feasibility studies of these types of systems could be useful decision-making tools. However, accurately predicting the long-term profitability of such investments is difficult due to the project’s dependence on multiple external factors and thus requires the use of a robust scientific model and careful precision of climatic and economic parameters to achieve an accurate result. Therefore, the purpose of this study is to perform a prefeasibility study of a possible SWHS in the Cape Town area and to evaluate the sensitivity of various parameters to the long-term ability of the project to produce energy cost savings. In this study, the technical and economic prefeasibility of installing a collective domestic SWH system in an apartment building is evaluated using the RETScreen Clean Energy Project Analysis Software, an advanced model equipped to analyze feasibility and energy performance of clean energy projects. A prefeasibility study of this nature is not currently available for South Africa in the literature, although there are similar types of feasibility studies for other locations throughout the world including Taiwan (Lin et al. 2015), Morocco (Allouhi et al. 2015), Jordan (Kablam 2004), Oman (Gastli and Charabi 2011), and Serbia (Stevanovic and Pucar 2012).

In this project, the RETScreen software was used to perform energy and economic feasibility analyses on a glazed flat-plate SWHS with an electrical coil for auxiliary heating. The SWHS is designed for a new flat roof apartment building with nine domicile units, located approximately 20 km southeast of the city center and near the Cape Town International Airport. Hardware coefficients of performance are obtained for SWH units that are available for purchase in the Cape Town region, and pricing for these units and installations are provided by actual suppliers servicing the region.

The results of interest from this study include energy produced by the SWHS, energy costs avoided by using the SWHS, greenhouse gas (GHG) emissions avoided by using the SWHS, net present value (NPV), and internal rate of return (IRR) of the investment, as well as sensitivity of these results to parameters of the project such as changing electricity costs, loan interest rates, or government subsidy amount.

Nomenclature

SWH	Solar water heating
SWHS	Solar water heating system
NPV	Net present value
IRR	Rate of return
GHG	Greenhouse gas
f	Solar fraction
F_R (τα)	Collector heat removal factor
$F_R U_L$	Collector heat loss coefficient [W/(m^2 K)]
H_T	Monthly average daily radiation incident on the collector plane
T_a	Monthly average ambient temperature
T_w	Hot water temperature
T_m	Monthly average water supply temperature
C_a	Actual storage capacity
C_s	Standard storage capacity

2 Literature Review

The presence of similar feasibility studies for SWHS in the literature can be noted as early as 2002, when Kablam (2004) performed a technoeconomic analysis for a SWHS in Jordan. In this study, a model was developed to determine the economic feasibility of a SWHS with an electric coil as an auxiliary fuel as compared to the base case of a conventional gas-powered water heater. It was determined that the SWHS remained economically preferable if the auxiliary electric coil was used for less than 120 days out of the year.

A study that is very similar in goal and scope to the current project was done by Gastli and Charabi (2011), who performed a full RETScreen analysis on a SWHS in Oman. In this study, the SWHS was compared to the base case of a conventional electric-powered water heater. The project for a four-person household was assumed to be financed 50% by government subsidies and 50% by the household. The pre-tax IRR for assets was calculated to be 12.2%, and the equity payback period was found to be 8.5 years. In addition, the net annual GHG emission was reduced by 3.6 tCO_2 equivalents.

There is also another study based on RETScreen aimed at determining the financial feasibility of a SWHS in Serbia (Stevanovic and Pucar 2012). This study performed a RETScreen analysis in six Serbian cities for a SHWS for a household of four people. For a government subsidy of 50% of initial costs, equity payback period ranged from 4.7 to 6 years depending on the location. In addition, this study also made a financial analysis to determine the most appropriate level of government subsidies for the project.

3 SWHS Prefeasibility Study in Cape Town

3.1 SWHS Design

The purpose of this project is to determine the feasibility of a typical SHWS in the Cape Town area. Since South Africa's public utility ESKOM has implemented grants of 40% of initial costs, it is in the public interest to demonstrate that these types of projects can be profitable and to determine financial indicators, such as equity payback period, IRR, and NPV. These results are here calculated using the support tool RETScreen, which comprises several types of analyses: energy model, GHG emission, reduction, cost, financial, and risk analyses.

In order to accomplish these objectives, it is necessary to design a SWHS with components that can be obtained in the region. For this project, a SWHS is conceived for the collective water heating of an apartment building. The area chosen for the placement of this system is near the Cape Town International Airport, as shown in Fig. 1. This location was chosen due to the abundance of meteorological solar irradiance data available for this area. Table 1, shows meteorological data for this area used by the model.

The apartment building is chosen to be a new flat-roofed structure with adequate space to accommodate the SWHS collectors and storage tanks. The SHWS comprises 20 glazed flat-plate solar panels, each with a gross area of 2.14 m^2, a 150-L storage tank, and a thermosyphon passive heat exchanger from the Jiangsu Sunrain Solar Energy Company. A thermosyphon heat exchanger uses the natural

Fig. 1 Geographic location of SWH project (Google Earth 2015)

Table 1 Meteorological data for Cape Town project area provided by RETScreen

Month	Air temperature	Relative humidity	Daily solar radiation – horizontal	Heatingdegree-days
	°C	%	KWh/m^2/d	°C-d
January	20.4	68.0	7.72	0
February	20.4	69.9	7.05	0
March	19.2	72.6	5.86	0
April	16.9	76.6	4.17	33
May	14.4	79.6	2.97	112
June	12.5	79.9	2.45	165
July	11.9	78.9	2.62	189
August	12.4	78.6	3.40	174
September	13.7	76.6	4.75	129
October	15.6	71.6	6.09	74
November	17.9	68.9	7.48	3
December	19.5	68.4	7.85	0
Annual	16.2	74.2	5.19	879

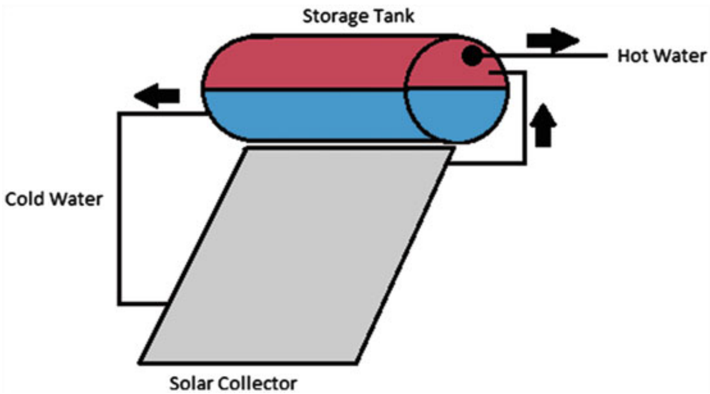

Fig. 2 Thermosyphon passive heat exchange, glazed flat-plate SWH

circulation of warm and cool water to direct flow through the solar collector and to the hot water output of the unit. Figure 2 shows the general principle of such a unit. The apartment building has nine domicile units, with four occupants each. It is assumed that each household member consumes an estimated 60 L of hot water per day (Donev et al. 2012).

An important parameter in the feasibility of a SWHS project is the electricity rate. South Africa has historically had low electricity tariffs due to abundance of coal reserves, consistent government subsidies, and centralized control of both coal supply and electricity production (de Groot and Sebitosi 2013). The electricity tariffs for domestic households of the City of Cape Town are indicated in Table 3.

3.2 Energy Model

The RETScreen energy model calculates the solar fraction f in order to determine the amount of energy produced by the SWHS. The solar fraction refers to the amount of heating demand that is met by the SWHS. The solar fraction is calculated in the following manner (Stevanovic and Pucar 2012):

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \tag{1}$$

where X and Y are determined as follows:

$$\begin{aligned} X &= \frac{A_C F_R U_L (T_{ref} - T_a)^*}{L} \left(\frac{C_a}{C_s}\right)^{-0.25*} \frac{(11.6 + 1.18T_w + 3.86T_m - 2.32T_a)}{(T_{ref} - T_a)} \\ Y &= \frac{A_C F_R (\tau\alpha) H_T N}{L} \end{aligned} \tag{2}$$

where T_{ref} is 100 ° C, L is the total monthly heating load, C_a is actual storage capacity, C_s is standard storage capacity, N is the number of days in the month, A_c is the collector area in m^2, F_R $(\tau\alpha)$ is the collector heat removal factor, $F_R U_L$ is the collector heat loss coefficient in Wm^{-2} K^{-1}, H_T is the monthly average daily radiation incident on the collector plane, T_a is the monthly average ambient temperature, T_w is the hot water temperature, and T_m is the monthly average water supply temperature.

Table 2 gives the necessary input parameters used for this SWHS.

Table 2 Parameters used in energy model of SWHS

Parameter	Value	Unit
Number of units	9	
Occupancy rate	100	%
Daily hot water use	2160	L/d
Temperature of heated water	60	°C
Operating days per week	7	
Slope of collectors	30	Degrees
Aperture area per solar collector	1.86	m^2
Gross area per solar collector	2.14	m^2
Fr (tau alpha) coefficient	0.67	
FrUL coefficient	4.62	W/m^2/°C
Number of collectors	20	
Storage capacity/solar collector area	70	L/m^2
Electricity rate	0.11	€/kWh

Table 3 Residential electricity pricing in 2014/2015

Units received (kWh/month)		Tariff (cents/kWh)	
		Rand	Euros
Lifeline (<450)			
First 50 kWh		Free	
Block 1	0–350	96.12	7.1
Block 2	350–450	233.30	17.3
Domestic (> 450)			
Block 1	0–600	153.63	11.4
Block 2	600+	186.81	13.8

City of Cape Town (2014a, b)

3.3 Electricity Pricing

In studying this feasibility for SWHS, electric heaters are considered as the base case with the cost of electricity being the fuel in comparison with the cost of solar radiation that is free. Electricity tariff in Cape Town is set by the City of Cape Town Electricity Services, with different prices being set depending on the expected consumption of the residence (City of Cape Town 2014a, b). Table 3 shows the residential electricity pricing in place; however, the tariff used in modeling this case is that for a monthly consumption of 0–600 kWh as set in July 2014. This is after taking into account the consumption needs of the apartment model, especially regarding hot water consumption of 240 L/day. When using a rate of 5.1 kWh/100 L to increase water temperature from 16 to 60 °C (Thomson 2013), energy use for water heating could be up to 367 kWh/month. According to a survey by the (City of Cape Town and Du Toit 2013), electric water heater accounts for 30–50% of the domestic electricity bill of a household in Cape Town. Furthermore, this same survey presents that each household spends on average R764.66 (537 kWh) on electricity monthly.

According to the electricity services board of the city, the tariff is expected to increase by 9.92% in 2015 and 9.26% in 2016 (Rencontre 2013). However, although future tariff changes are expected to occur in a manner that cannot be readily modeled for the lifetime of the project, an escalation rate of 10.0% is factored in by assuming that the annual increase in electricity price during the lifetime of the project will remain at about the same rate for the 2015 and 2016 projections. Additionally, a trend analysis of the rate of price increase from 2006 to 2014 was made to define a cap of 15.34% while evaluating the sensitivity of the project to electricity price escalation.

3.4 System Cost

The selection of the system and its cost plays a fundamental role in the feasibility of the project. In defining the cost of the selected system, estimates were obtained

Table 4 Cost estimates for the selected SWHS

Item	Cost	
	Rand	Euros
Feasibility study	8605	559
SWHS (×20)	249,517	18,464
Engineering and Installation	146,356	10,830
Training and Commissioning	770	50
Unskilled Labor	847	55
Total	406,096	29,958

1 rand = 0:074 euros; Costs are inclusive of 14% VAT

from a Chinese supplier, two Eskom-approved suppliers in Cape Town, and an agent with the SWH division of Sustainable Energy Society of Southern Africa (SESSA). However, the estimate presented by one of the suppliers in Cape Town was used since they provided a breakdown of the individual components in the overall cost, as detailed in Table 4. Furthermore, the difference in the cost estimates from these four sources was small, and a contingency of 10% was factored into calculations. Apart from the system cost, it was also important to factor in the installation and maintenance costs as well as the costs of auxiliary systems such as pipes and pumps.

3.5 *Financing*

As with most clean energy projects, the initial costs are often a barrier. According to a market research conducted by the City of Cape Town in 2013, 67.9% of respondents are desirous of SWHs; however, the SWH unit installation and upfront costs are given as the main hindrances to installing one. Duly noting that 67.2% of interviewed persons consider upfront cost as a major drawback (City of Cape Town and Du Toit 2013), in coping with this, Eskom offers a SWH rebate program to cover the initial costs. This rebate is about 40% of the cost of the solar collector unit and ranges from €243 to €663 (R3280 to R8964) for each unit installed that meets certain specified conditions. The calculation of the exact amount depends on the type of system installed (ESKOM 2012). The system considered for this study meets the criteria for benefiting from the rebate and is estimated as €7640 (€382 per unit).

However, considering that 54.2% of persons will be motivated to obtain a system only if there are no upfront costs and that 62.5% would like to pay less than €148 (R2000) for the initial cost of the system (City of Cape Town and Du Toit 2013), financial calculations of the viability of the project are made with the assumption that the remainder of costs not covered by the rebate is taken as a bank loan to be paid over a 5-year term. The complete financial parameters for the project are specified in Table 5.

Table 5 Financial parameters for the feasibility study simulation

Financial parameter	Value	Unit
Inflation rate[a]	5.3	%
Fuel escalation rate[b]	10.0	%
Debt ratio	60.0	%
Discount rate	9.0	%
Debt term	5	Years
Debt interest rate[c]	11.0	%
System lifetime	25	Years
Government rebate for 20 units[d]	7640	€

[a]Triami Media BV (2014)
[b]Rencontre (2013)
[c]Trading Economics (2014)
[d]City of Cape Town (2011)

4 Results and Discussions

Following the simulation of these design parameters as described in the preceding sections using RETScreen, the results obtained are as follows.

4.1 Energy Savings

The designed SWHS provided 17 MWh of heating per year, which is equivalent to a solar fraction of 42%. The use of the system resulted in an electricity consumption of 23.3 MWh, compared to the base case consumption of 40.3 MWh. This represents an electricity savings of 17 MWh per annum, which is equivalent to €1934.

4.2 Emissions Reduction

The amount of emissions (normalized to tons of CO_2) estimated from the use of the SWHS is 24 tCO_2 equivalents, while with the use of electricity for water heating, it was 41.5 tCO_2 equivalents. This results in a saving of 17.5 tCO_2 equivalents, which is equivalent to 3.2 cars taken off the road in a year.

4.3 Financial Analysis

The results obtained from the simulation of the financial parameters for an investment in the SWHS taking into consideration the present situation in South Africa and the projections described above in the Financial discussion section (and Table 5

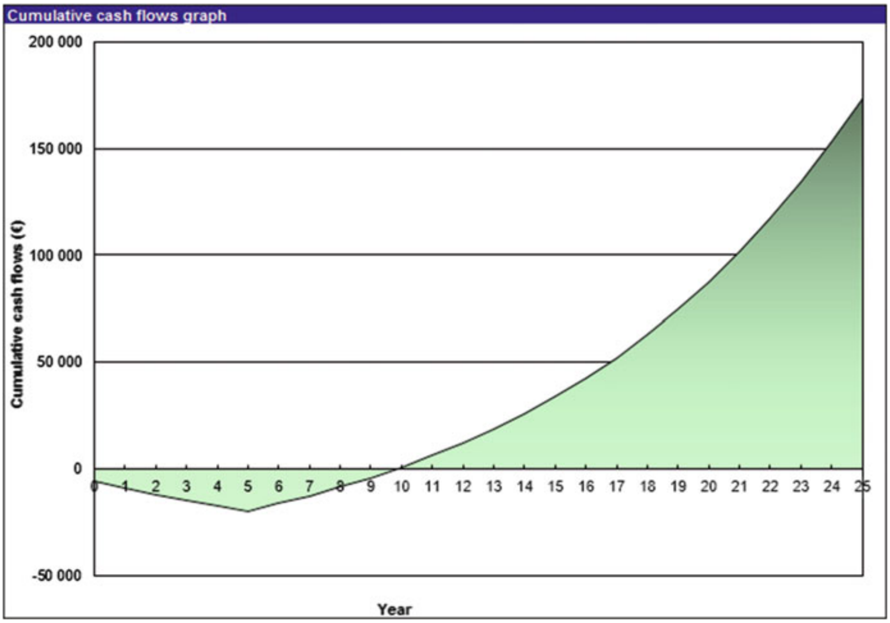

Fig. 3 RETScreen cumulative cash flow graph

above) show that the net present value (NPV) on the investment is €27,028 with an internal rate of return (IRR) of 17.3% and an equity payback time of 9.9 years. The benefit–cost ratio of the investment is 3.05. Figure 3 below shows the progression of the cumulative cash flow from the investment over time.

With all the parameters employed for this simulation, it can be seen that the parameter with the highest influence on the profitability of this investment is the cost of the electricity, as seen from the relative impact graph shown in Fig. 4, based on a Monte Carlo analysis of 500 combinations of possible scenarios with an uncertainty of 10%.

From the relative impact shown in Fig. 4, it can be seen that the cost of fuel (which is the local cost of electricity) has a high impact on the viability of this project. This parameter was analyzed by seeing how the variation of the escalation rate of electricity will affect the NPV, the payback time, and the IRR. Table 6 shows how these values vary with the different escalation rates of electricity.

Another important parameter is the availability of rebate. Presently, the rebate is 40% of the cost of the equipment, which amounts to €7386. Figure 5 shows the effect a reduction or removal of this rebate will have on the after-tax IRR of the investment. The removal of the rebate will give an after-tax IRR of 13.7%, a payback period of 11.2 years, an NPV of €19,642, and a benefit–cost ratio of 2.49.

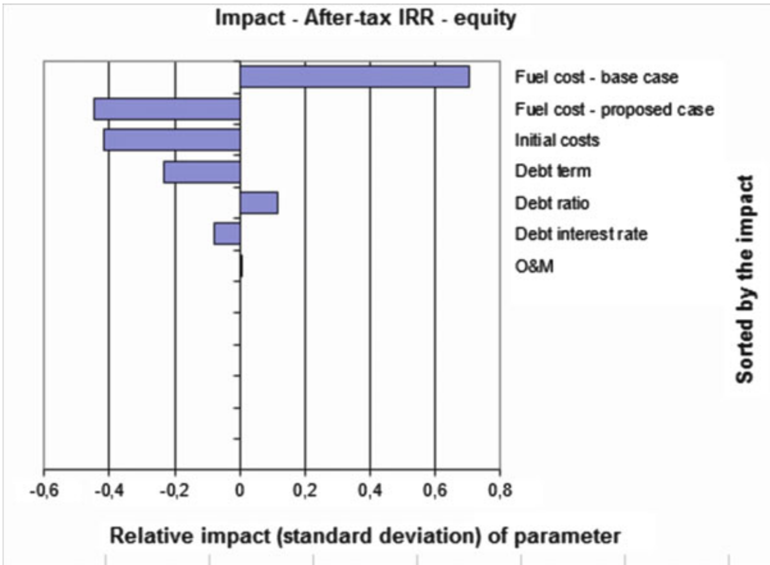

Fig. 4 RETScreen tornado diagram of sensitivity analysis on after-tax IRR

Table 6 Effects of changes in fuel escalation rates on financial returns

Fuel escalation rate	After-tax IRR asset (%)	Benefit–cost ratio	Equity payback (years)	NPV (€)
5.0	10.5	1.25	12.3	3,294
7.5	13.9	1.99	10.9	13,046
10.0	17.3	3.05	9.9	27,028
12.5	20.7	4.59	9.1	47,292
15.0	24.2	6.85	8.4	76,909

5 Conclusions

With 42% of energy savings and a matching percentage in emissions reduction, it is very reasonable to say that the justification behind the technical benefits of SWH have been validated in the case of an apartment building similar to the one defined in this work in the City of Cape Town, South Africa.

The designed SWHS yielded a yearly 17 MWh in energy savings, 17.5 tCO_2 equivalents emissions reduction, along with a net present value (NPV) on the investment of €27,028, with an internal rate of return (IRR) of 17.3%, and an equity payback period of 9.9 years.

Nevertheless, the current ESKOM rebate scheme plays a pivotal role in the attractiveness of investments in such SWH systems. The 40% rebate scheme

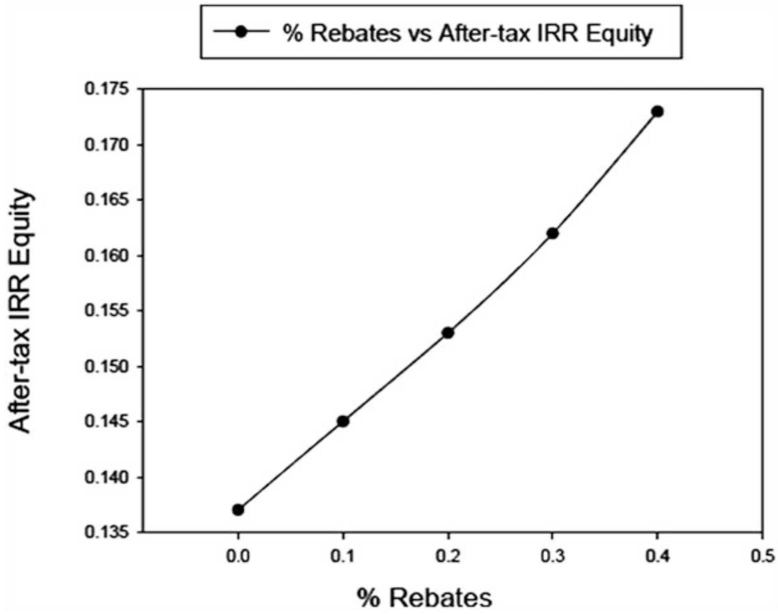

Fig. 5 After-tax IRR vs. rebates sensitivity analysis

(on initial investment) is responsible for a 1.3-year reduction of the payback period and a 5% reduction in the after-tax IRR.

Although the rebate scheme was significant as 67% of the residents of Cape Town indicated concerns regarding the initial investment, the outcomes of the study highlight a greater financial sensitivity to the fuel escalation rate. Generally, the application and adoption of SWHS in Cape Town has yielded positive overall outcomes.

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