THE POTENTIAL FOR SOLAR HEAT IN THE CAPE FOOD AND BEVERAGE INDUSTRY

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Abstract:

The food and beverage industry (F&BI) is one of the largest industries in the Western Cape and thus one of the largest energy consumers. Currently, process heat is mainly generated from coal, heavy fuel oil (HFO) and electricity. This paper investigates whether current solar water heating (SWH) technology can supplement conventional energy use within the Western Cape F&BI. With this aim, two separate areas were investigated, namely, the potential for such technology in terms of market size (or installed capacity) and the cost of implementing such technology. Based on the length of production periods at three food and beverage (F&B) facilities in the Western Cape, coupled with the low costs of fossil fuels, it was concluded that SWH systems are currently not financially viable. The paper therefore predicts at what price (of conventional energy, namely, coal and electricity) these technologies may become competitive. Data from three local F&B companies was employed to model the typical energy consumption profiles of companies in this industry. The program RETScreen was used to model three different types of SWH systems, whose output was then used in lifecycle cost analysis (LCA). The net present value of SWH systems was used as one criterion to judge the economic competitiveness of these technologies.

Keywords: solar water heating, lifecycle cost analysis, food and beverage industry, industrial process heat.

1. Introduction

South Africa has a very high energy intensity compared to that of developed nations, with the country's industries consuming on average 36% of the total primary energy supply (DME, 2009). In the Western Cape, the industrial sector consumes as much as 47% of primary energy (Department of Environmental Affairs and Development Planning: Western Cape, 2008). A large portion of this consumption generates thermal heat. Economically, the food and beverage industry (F&BI) is one of the largest industries in the Western Cape and one of the largest consumers of energy in the province as well.

Historically, energy costs in the F&BI have been low, i.e. less than 10% of production costs (DME, 2002), but in the current energy climate, these costs are due to rise sharply. Companies need to adapt, either by initiating energy efficiency measures (CCT, 2003) or by using renewable energy technologies.

Solar heating systems (SHSs) offer a way for industry to reduce their reliance on fossil fuels. Many of the processes in industry run continuously and are therefore well suited to augmentation with solar heat. The F&BI consumes a large proportion of thermal energy, much of which (60%) is required at temperatures below 250°C, which can easily be provided by solar water heaters (SWH) (Vannoni, Battisti, & Drigo, 2008).

The main aim of this study is *to establish whether there is potential for solar heat to provide energy to the F&BI, using the Western Cape as the focal point*. To achieve this objective, two main subtasks had to be satisfied: assessing the potential for this technology in terms of installed capacity as well as determining the cost at which it can be implemented.

To calculate the cost of implementing a SHS[1], information was gathered from three large F&B manufacturers about their energy consumption. Suitable solar technologies were chosen to supplement this energy consumption. The data was then analysed within an energy modelling package. A similar approach has been followed by other authors (Benz et al, 1999; Kalogirou, 2003; Kulkarni et al, 2008). The annual energy output from these systems was then used as an input for the LCA (lifecycle cost analysis), which was used to determine the viability of using a SHS (Kalogirou, 2004).

In order to establish the potential for solar heat in the Western Cape F&BI, one must establish the total size of energy consumption within this industry before calculating what percentage could be supplemented with SHSs.

Various sources were used to determine the energy consumption within the F&BI of the Western Cape (Winkler et al, 2006; CCT, 2003; Sustainable Energy Africa & UCT's Energy Research Centre, 2010). No disaggregated energy balances, breaking down energy consumption to a sub-sector level, are available for the province.

The total primary energy consumption for industry in Cape Town, for the year 2000, was 25.4 PJ [Peta-Joules] (Winkler et al, 2006), viz. 24% of the total energy demand in Cape Town. The F&BI consumes 2.7 PJ or 11% of this industrial percentage. However, these figures use the year 2000 as a base year and the figures are only for the City of Cape Town. In a study done for the Western Cape Department of Economic Development and Tourism (Kowalik & Coetzee, 2005), the total industrial energy demand for the Western Cape was calculated as 27.8 PJ, thus slightly higher than that of Cape Town's (25.4 PJ). Kowalik and Coetzee (2005) confirm that the provincial industrial energy demand is higher for the Western Cape, namely, 27.8 PJ; they state, however, that this figure is not accurate[2] and that it is difficult to obtain a disaggregated balance of energy use in the Western Cape.

Thus far in South Africa, studies on SWH have limited themselves to calculating and forecasting the demand from residential and commercial sectors (Holm, 2005) and to assessing the state of the local SWH manufacturing industry (Holm, 2005; Theobald & Cawood, 2009).

Two international studies have investigated the potential for using solar heat for industrial processes (AIGUASOL Enginyeria, 2001[3]; Vannoni, Battisti, & Drigo, 2008). The former sets out the current system costs and what they need to be in order to be competitive with conventional heating systems (AIGUASOL Enginyeria, 2001). The later was intended to serve as a guide, which would enable local authorities to develop the necessary policies and instruments to help implement the use of solar thermal energy within the industrial sectors of their respective countries.

2. Solar Radiation Data

The "Solar Radiation Data Handbook for Southern Africa" (Eberhard, 1990) and NASA's "Surface meteorology and Solar Energy" website, which uses detailed satellite and ground data obtained over the past 22 years (NASA, 2009), were consulted in this study. Both studies indicate the long-term average of the solar irradiance levels, as data has been recorded over many years, hence reflecting the effects of local climatic conditions. The NASA data is used by the modelling software RETScreen (Natural Resources Canada, 2010) in the solar energy modelling spreadsheets.

3. Solar Collectors

Three types of solar collector were considered for this study, namely:

- Flat plate collectors (FPC)
- Evacuated tube collectors (ETC)
- Parabolic trough concentrators (PTC)

Whenever possible, local manufacturers were consulted first, then local distributors, and finally (when nothing was available locally), international suppliers. Many local manufacturers are only SABS tested (this is insufficient for solar modelling of large scale solar systems), and the collector performance parameters necessary for RETScreen are not supplied in these tests. Collectors tested by European and American authorities, however, do supply the necessary parameters (see Table 1).

Table 1: Solar collector parameters used in modelling SHSs

Description	FPC	ETC	PTC
Aperture Area Per Collector (m^2)	2.03	1.39	28.89
Gross Area Per Collector (m^2)	2.15	2.34	28.89
Cost (R/m^2) Lower Bound	4,320	6,130	12,450
$F_R(\tau\alpha)_n$ (Heat gain coefficient)	72.13	43.43	68.5
F_RU_L (Heat loss coefficient)	4.325	1.087	0.4
Temperature coefficient for F_RU_L	0.0117	0.0043	0.0015
Capacity Cost (R/kW)	6,134 – 9,285	8,757 – 11,671	17,786 – 21,886
Area Cost* (R/m^2)	4,230 – 6,500	6,130 – 8,170	12,450 – 15,320

*This is based on aperture area and does not take into account area needed to avoid shading

The costs are based on the aperture area. The area and performance data for the FPCs is based on averages from four collector manufacturers/distributors. The ETC data is an average of the data from one distributor and from the literature (Kalogirou, 2003). The PTC data comes directly from the manufacturer (Minder, 2010).

4. Solar thermal processes

This section highlights the theory used to calculate the useful heat gain of the solar collectors, and it also describes how the test data from certification authorities is used to calculate this quantity.

The following equation predicts the useful heat gains from solar collectors (Duffie & Beckman, 2006):

$$Q_u = A_c F_R [S - U_L(T_i - T_a)] \qquad \text{(eq. 1)}$$

where A_c is the area of the collector in m^2, F_R is the heat removal factor, S is the solar radiation absorbed by the collector in J/m^2, U_L is the overall heat loss from the collector[4], and T_i[5] and T_a are the inlet fluid and ambient temperatures respectively. This equation can be applied to most types of collectors.

The useful heat gain is calculated as a function of the collector inlet temperature by using Equation 1. This is a convenient method for analysing SHSs, but not entirely accurate. The heat removal factor F_R therefore adjusts the useful heat gain of the collector from what it would have been if one simply assumed that the absorber was at a constant temperature equal to the fluid inlet temperature, to what it is in reality (Duffie & Beckman, 2006).

Most testing authorities define the instantaneous efficiency of a solar collector, which is the ratio of the useful heat gain to the solar radiation falling on the collector area, as follows:

$$\eta_i = \frac{Q_u}{A_c G_T} = F_R(\tau\alpha) - \frac{F_R U_L (T_i - T_a)}{G_T} \qquad \text{(eq. 2)}$$

where η_i is the instantaneous efficiency and S has been replaced by the product of G_T and $(\tau\alpha)$. In this case, $(\tau\alpha)$ is the transmittance-absorptance product of the solar collector. Essentially, it is the transmittance-absorptance product of beam radiation falling on the collector (Duffie & Beckman, 2006). G_T is the total amount of solar radiation falling on a collector's aperture.

The instantaneous efficiency of a collector is a misleading term when used in isolation to determine the amount of heat collected by a SHS. The above model, Equation 2, implies a simple linear relationship between the instantaneous efficiency and the operating conditions, $\frac{T_i - T_a}{G_T}$. But in reality, data plotted using Equation 2 can be scattered, and the variables F_R, U_L and $(\tau\alpha)$ are not constant in the operating conditions of the FPC. Scatter in the data is due to temperature dependence, wind effects and angle of incidence changes (Duffie & Beckman, 2006). This leads to the following equation, which describes the instantaneous efficiency of solar collectors as a function of the operating conditions. The resulting equation implies a quadratic relationship:

$$\eta_i = \eta_o - a_1 \frac{\Delta T_m}{G_T} - a_2 \frac{\Delta T_m^2}{G_T} \qquad \text{(eq. 3)}$$

where the equation is in the European format, i.e. the true mean temperature difference between the absorber and ambient conditions is used. In this format, η_o is equivalent to $F'(\tau\alpha)$. This equation is used by most solar modelling packages in either of the two forms (European or US), and therefore it is important to make sure the data entered is in the correct form for the corresponding programme.

Equation 4 below is an adjusted form of Equation 1 that takes into account the changing angle of the sun over the seasons, and the term $K_{\tau\alpha}$ is known as the angle of incidence modifier:

$$Q_u = A_c F_R [G_T K_{\tau\alpha} (\tau\alpha)_n - U_L (T_i - T_a)] \qquad \text{(eq. 4)}$$

Because the product $(\tau\alpha)$ is calculated under test conditions, when beam radiation is strong, it does not give such an accurate approximation of the conditions experienced by the solar collector when the sun is low in the sky or when cloud cover is predominant. At these times, diffuse and reflected radiation make up the larger portion of the heat collected by the absorber.

5. Technical potential for SWH

The technical potential of a specific technology is simply a measure of the quantity of a technology that can be implemented with current knowledge, without regard for economic constraints (Nadel, Shipley, & Elliot, 2004), and assuming that all available opportunities are exploited.

The technical potential for a process with a constant demand throughout the year is bounded by a solar fraction of 60%; this is a similar methodology to that used in the POSHIP study (AIGUASOL Enginyeria, 2001). Another limiting factor is the available roof and ground space of the plant.

The reason why 60% was chosen as the ceiling for the technical potential is that solar fractions above this require increasingly large amounts of / require much more thermal storage. This invokes the law of diminishing returns. It makes economic sense to have a small amount of storage available for load fluctuations and for weekend shutdowns. But in order to supply a large solar fraction (>60%), the amount of storage required increases, whereas the returns in the form of useful process heat diminish. Storage has only been considered in the case of Company C (COMC), which required 190,000 litres of storage, as all the heating is needed at night. This night time load will thus be catered for, but at the expense of increased system costs.

6. The cost of solar thermal energy

The first task was to collect information about industrial processes common to the F&BI. Emails were sent out at random to F&B manufacturers who have plants in the Western Cape. A diverse range of companies within the sector was contacted to ensure that the sample was representative of the many different manufacturing processes within the industry. Three companies (Companies A, B and C, herein referred to as COMA, COMB and COMC respectively) were willing to participate in the study and supplied data as to the mass flow rates of thermal energy consumed in various processes around their facilities.

The next step was to collect data from the various solar collector manufacturers/distributors and to derive relevant collector specifications that could be entered into a solar model, see Table 1.

COMA produces oil and margarine products, COMB is a fruit canning factory and COMC processes vegetables.

The system design for COMA and COMB is simply an indirect feed system that continuously pre-heats boiler feed water using a heat exchanger between load and the solar system. In COMC, the amount of energy collected in the storage tank is equivalent to 60% of the useful heat demand needed by this system. The design for this system is an indirectly fed system where a heat exchanger is used between the storage tank and the solar system.

6.1 Collector types and processes

The process chosen for the basis of comparison with the different collector types is the heating of boiler make-up water. The primary reason for choosing this process is that it is common to all three of the factories.

Furthermore, boiler make-up water can be a considerable part of energy consumption in some plants where a large portion of water may not be returned to the boiler for reheating. This fresh supply of water has to be heated up from an ambient temperature to the boiler operating temperature. Pre-heating this water to between 80°C and 90°C means that the boiler will consume less fuel and that it just has to top-up the heat to the desired operating temperature.

6.2 Economic tool for comparison of systems: net present value

The economic tool used to compare the costs of the different solar collector types in supplying the boiler make-up water is the LCA, which compares the net present values (NPVs) of these systems. The NPV analysis takes into account the time value of money, as well as the effect of discount rates. The economic indicators used are: inflation rate 6.2%; interest rate 12.5%; discount rate 4.43%. The loan amount has been stipulated as 75% of the investment cost, as some capital outlay would have to be provided for by the plant applying for a loan. Renewable energy investments are relatively new in South Africa and there is no consensus amongst finance experts as to the financial parameters that should be used for these types of investments.

6.3 Fuel costs

The following fuel costs have been used in the sensitivity analysis of the LCA results. The first two electricity price increases reflect the MYPD 2 increases that have been approved by NERSA (NERSA, 2009). The prices in the first column are average prices currently available to the F&BI. The coal price has been increased on a Rand per tonne basis, and the conversion to a price per unit of energy has been shown for comparison with the electricity price (the Gross Calorific Value [GCV] used is 27.317 MJ/kg).

Table 2: Present and future fuel costs

	Present Energy Costs	Future Possible Energy Costs				
Electricity Price (R/kWh)	**0.416**[7]	0.52	0.65	0.75	0.80	0.9
Coal Price (R/tonne)	**1,100**	1,250	1,500	1,750	2,000	2,500
Coal Price (R/kWh)	**0.14**	0.165	0.2	0.23	0.26	0.33

7. Results

The results of the LCA and potential for solar heat are discussed.

7.1 The potential for solar heat to supply thermal energy in the Western Cape

The technical potential for solar heat in the Western Cape F&BI is ***12 PJ***, which is equivalent to 9% of the total industrial consumption in the Western Cape for the year 2007. The base year of the “Energy Scenarios for Cape Town” has been used (2007).

Due to the lack of disaggregated energy consumption data, the main sources of data for the size of the City of Cape Town’s F&BI are air quality data published by the City of Cape Town and aggregated fuel sales figures. The figures presented in these studies are at best estimates of the size of the energy consumption within the various subsectors.

The F&BI consumed 35 PJ of energy within the Western Cape for the year 2007, which is equivalent to 28% of the industrial energy consumption of the province [267 PJ, (Department of Environmental Affairs and Development Planning: Western Cape, 2008, p. 14)]. Figure 1 shows a breakdown of the energy consumption within the Western Cape's F&BI. Of this energy / this category, only coal, paraffin and HFO have been considered in calculating the technical potential for SHSs.

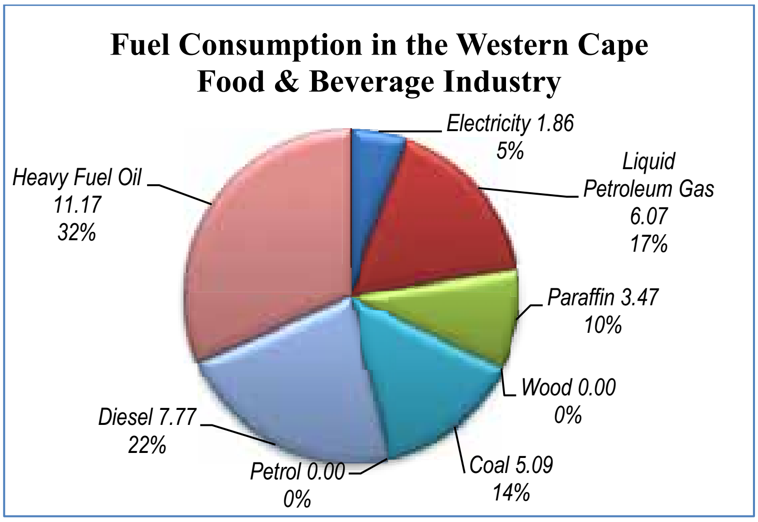

Figure 1: Fuel consumption in the Western Cape F&BI (PJ) and the relative share of each fuel of the total

7.2 The lifecycle cost analysis of the original scenario

In the Original Scenario, the LCA looked at the process of pre-heating boiler make-up water. The systems modelled are indirect feed systems, where municipal-supply water in a secondary loop is pre-heated by the HTF (heat transfer fluid) of the SHS by using an efficient flat plate heat exchanger. COMA and COMB do not store this heat; however, the thermal heat generated by the SHS of COMC is only needed at night, so it must be stored.

The investigation into pre-heating boiler feed water has been performed over a range of temperatures to see the effect of temperature on the LCA. Likewise, the performance of the PTCs has been evaluated to see whether they function better at generating medium temperature steam (10 bar saturated steam at 180°C) or pre-heating boiler water. The other two types of collectors do not perform as efficiently as the PTC at generating medium temperature steam (Kalogirou, 2003) and therefore have not been analysed at such high temperatures.

Table 3 summarises the results of the LCA as well as the annual solar outputs, system sizes, and investment costs. The pre-heating of boiler make-up water is a continuous process during the production periods of the companies surveyed, even in the case of the plants with seasonal production periods. The length of these production periods varies by plant.

The following general trends can be observed from Table 3, which summarises the results obtained from the LCA by using the financial constraints of the Original Scenario:

The LCA yielded negative NPVs for all but three of the proposed SHSs. The payback periods are long and far exceed the maximum period at which industry deems them suitable for investment, i.e. 18 months or less (DME, 2002).

Both the NPV and payback period of the options for the COMA plant are more favourable than are those of the COMB and COMC plants. This is due to the shorter seasonal production periods of the last two plants (four and six months respectively). Plants that operate SHSs for less than six months of the year tend to be uneconomic, i.e. to have low NPVs and long payback periods. This outcome is confirmed by the POSHIP study: "Systems with only seasonal utilisation (less than 6 months operation a year) are in general not economic" (AIGUASOL Enginyeria, 2001, p. 131).

The payback period of the options for the COMC plant are on average shorter than are those of the COMB plant, which seems to conflict with the above statements. The reason for this apparent contradiction is that the plants use different fuels to generate thermal energy. The COMC plant uses electricity, whereas the COMB plant burns coal, therefore in this case the difference in production periods has less effect on the NPVs than the difference in fuel prices does.

Table 3: Results of the LCA and RETScreen modelling for the pre-heating of boiler make-up water

Company/ Collector Type		Output Temperature (°C)[i]	Water Requirements (L/d)	BAU Energy Requirement (MWh)[ii]	Annual Output (MWh)[iv]	System Aperture Area (m²)	Investment Cost (1000s)[iii]	NPV (15 Years) (1000s)	Payback Period (Years)
COMA	FPC	90	144 000	4 525	2 694	1 827	R 8 086	R 705	14
	ETC	90	144 000	4 525	2 694	1 888	R 11 656	R -2 709	19
	PTC	90	144 000	4 525	2 730	1 560	R 19 423	R -10 031	29
	FPC	45	144 000	4 525	1 050	713	R 3 157	R 274	14
	FPC	60	144 000	4 525	1 598	1 082	R 4 797	R 418	14
	PTC	180	144 000	10 045	6 007	3 438	R 42 802	R -22 105	29
COMB	FPC	90	130 350	1 996	1 189	1 411	R 6 174	R -2 572	24
	ETC	90	130 350	1 996	1 189	1 411	R 8 896	R -5 176	33
	PTC	90	130 350	1 996	1 193	1 156	R 14 387	R -10 415	47
	FPC	45	130 350	1 996	448	524	R 2 324	R -968	24
	FPC	60	130 350	1 996	694	814	R 3 604	R -1 502	24
	PTC	180	130 350	4 485	2 683	2 600	R 32 371	R -23 877	47
COMC	FPC	45	240 000	1 200	413	1 027	R 4 551	R -1 570	22
	FPC	60	240 000	1 200	716	1 959	R 8 708	R -3 501	24
	ETC	60	240 000	1 200	716	1 672	R 10 250	R -4 977	28

[i] This is the output temperature from the SHS, which would be fed to the boiler.

[ii] Some of these figures have been rounded off to the nearest five.

[iii] This is the annual useful energy output from the solar system.

[iv] Investment costs are based on the aperture area of the solar field.

The second biggest factor that affects the LCA of the SHSs, besides the length of the operating period, is the fuel type and hence price of the fuel used in the conventional heating system. Electricity is currently far more expensive than coal, on an energy basis i.e. R/kWh (for a breakdown of the fuel prices used in this analysis, refer to Table 2).

COMA and COMB use cheap fossil fuels to generate thermal energy; even taking into account the system inefficiencies of the boilers, the results above clearly show that SHSs competing with coal are uneconomic. Even in the case of COMA, where the systems would be used continually throughout the year, the price of coal is so low that the energy savings provided by a SHS are not large enough to render the project economically feasible.

7.3 The results from the future fuel price scenario lifecycle cost analysis

The operating period or annual utilisation of SHSs and the fuel price are thus the two biggest factors affecting the financial viability of the SHSs. Future fuel price scenarios (FFPS) have been carried out by varying the fuel cost and annual utilization period for six of the SHSs listed in Table 3. There are two cases for each of the three collector types, so that the effect of rising coal and electricity prices can be examined for each collector type.

The FFPS is essentially a sensitivity analysis, in which many possible scenarios are modelled based on possible future conditions to help plan future energy investments. The SHSs are envisaged to supplement the use of fossil fuels, thereby making their consumption under higher energy prices sustainable. The options modelled are: COMC FPC 60°C (substitutes electricity); COMC ETC 60°C (substitutes electricity); COMB FPC 60°C (substitutes coal); COMB PTC 180°C (substitutes electricity); COMA ETC 90°C (substitutes coal) and COMA PTC 180°C (substitutes coal). See Table 2 for a breakdown of the fuel price increases used in the FFPS.

For each modelled in this scenario, the annual system utilisation was varied from one to twelve months, where one month is equal to 730 operating hours[8]. The annual plant utilisation starts in January. The LCA was applied to each individual operating period for each of the six options, and in turn, each of these was examined under 6 different fuel prices. This is equivalent to 432 different LCAs, which generates a large amount of data.

Having such a large spread of data increases the likelihood that the actual conditions present in the future will fall within the bounds of the analysis.

Each of the options is examined whilst varying both the fuel price and the annual utilisation (i.e. 72 data points per graph). 3-D surface graphs have been used to show the relationship between the three parameters, viz. fuel price, annual utilisation and NPV (at 15 years).

7.4 Discussion of the FFPS results

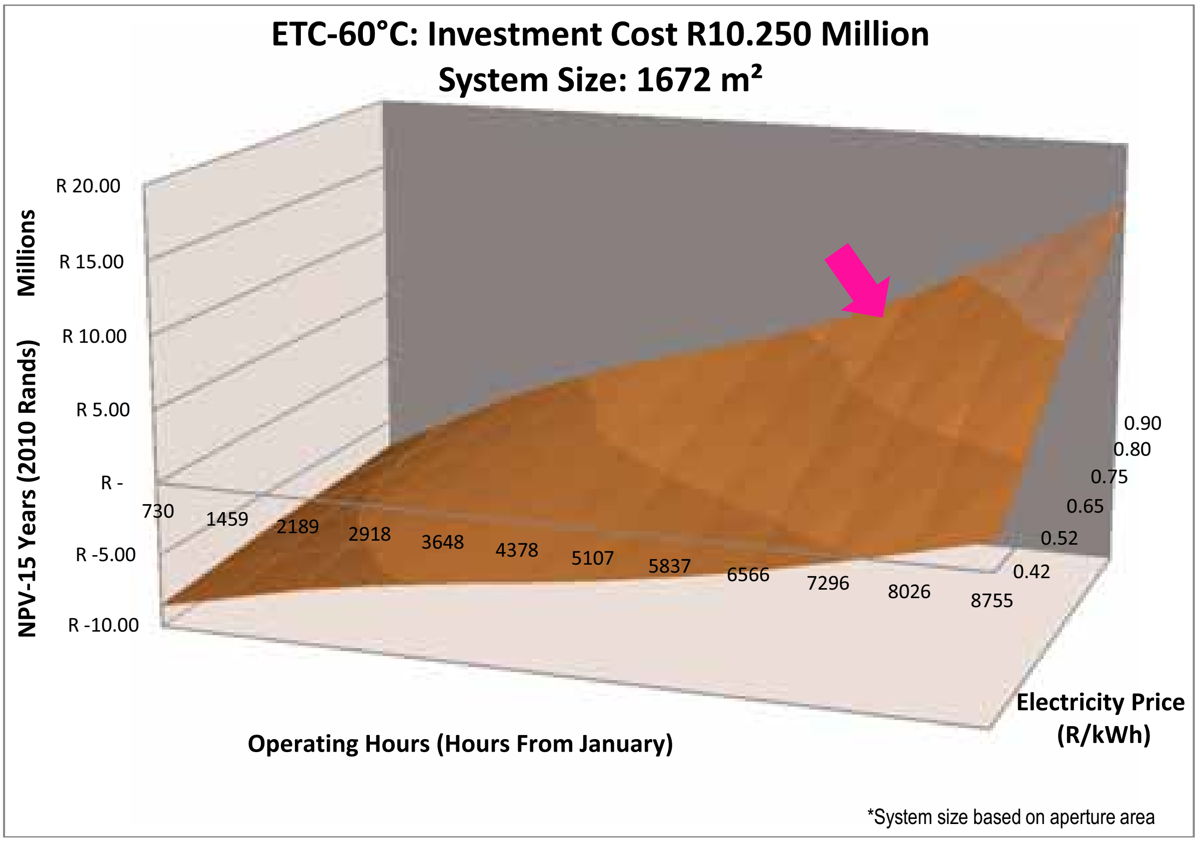

Figure 2: Results from the LCA for COMC FPC 60°C, where SHS supplements electricity

The ETC system, shown in Figure 2, has a NPV of R-4.98 million after 15 years (and a payback period of 28 years) under the Original Scenario. As stated previously, the main factor affecting the viability of this investment is the annual utilisation of the plant, as it only operates for four months of the year.For comparison with the results of the Original Scenario, increasing the electricity price to 0.9 R/kWh, while keeping the annual utilisation constant, only increases the NPV to R634 000 by the end of the project life. The payback in this case is 15 years, and investing the capital in the SHS provides a much lower return on investment than investing the same amount of capital in the bank (NPV of R27 million after year 15 at the same interest rate).

This option first becomes feasible when the electricity price is 0.65 R/kWh and the system is utilised for 12 months of the year. On Figure 2, this corresponds to the region marked by the arrow on the graph. The graph clearly shows the links between both fuel price and annual utilisation with the NPV of the system. The closer to the top right-hand corner one gets, the more profitable the investment becomes, and this area is thus named the region of feasibility.

It is evident from the analysis that a continuously fed FPC system (with high annual utilisation) that supplements electricity is by far the most economic SHS that can be designed currently. Unfortunately, none of the plants surveyed for this project meet these conditions exactly.

For example, under current electricity prices (0.416 R/kWh), an indirectly fed FPC SHS, designed to pre-heat boiler make-up water continuously, with an annual utilisation of 12 months and with an investment cost of R3.5 million would have a payback period of just under 6 years (using the same financial parameters as the Original Scenario). Therefore, under the next scheduled electricity price rise, systems operating under these constraints would be financially viable.

To summarise, out of the six options tested under the FFPS, only four of the systems offer real investment potential, whereas the other two options, namely COMA ETC 90°C and COMA PTC 180°C, never reach a point where the projects are financially viable. Even under the highest coal prices (2500 R/tonne), the systems only offer a payback of 7 and 15 years respectively.

The ETC and PTC systems do not become financially viable when supplementing conventional coal heating systems. The collector costs for both these systems are too high compared to the unit price of thermal energy derived from coal, even with boiler inefficiency taken into account. However, both collector types do become feasible when supplementing electricity use at 0.65 R/kWh (COMC ETC 60°C) and 0.75 R/kWh (COMB PTC 180°C).

Thermal storage decreases the competiveness of SHSs in two ways: directly, by increasing the costs of the system, i.e. that of the storage component, and indirectly, by requiring a larger collector area. The latter result arises from the fact, firstly, that thermal storage increases the amount of thermal losses and, secondly, that the temperature difference between the solar loop and the thermal storage is smaller than the difference between the solar loop and the incoming municipal water in a directly fed system. In other words, the heat transfer from the solar loop through the heat exchanger is less because the difference in temperature between the storage water and the water in the solar loop is less, which means that a larger collector area is needed to supply a similar amount of energy through the heat exchanger.

The increased costs imposed by importing the PTCs, decreases their financial viability. Under further investigation, the payback of the COMB PTC 180°C option decreases by two years if a lower collector system cost is used, viz. 10 090 R/m^2 instead of 12 450R/m^2, with an annual utilisation period of 12 months.

Although the costs of thermal storage and importation do increase the payback period of the systems, it is evident from the smaller magnitude of these effects, that the annual utilisation period and fuel price are still the most crucial factors influencing the financial viability of the SHSs.

For the output temperatures explored in this study, the supply temperature seems to have little impact on the financial viability of the systems. However, the POSHIP report (AIGUASOL Enginyeria, 2001) found that the temperature of the solar heat played a significant role in the financial success of the systems modelled. It is important to remember, however, that in their study conventional heat costs are in the range of 3-4.5 cents of €/kWh (2001 Euros) for HFO and LPG. This is equivalent to a fuel price of between 0.38-0.57 R/kWh (2010 Rands), which is considerably higher than the current cost of coal, with the upper range being more expensive than electricity currently. This may suggest a relationship between fuel price and the temperature of the solar energy supply that becomes more apparent when the fuel being substituted is more expensive.

8. Conclusions

The main objective of this project was *to establish whether there is potential for solar heat to provide energy to the F&BI in the Western Cape*. It was shown that the size of this potential, for fuel consumed in 2007, was ***12 PJ***, which is 9% of the Western Cape's total primary energy consumption. Consequently, solar heat can displace at least 12 PJ of primary energy consumption within the F&BI of the Western Cape, which is equivalent to 440 000 tonnes of coal a year (using a GCV of 27 MJ/kg) or 290 000 tonnes of oil[8]. Using the average energy collected by a square meter of FPC in Cape Town, one would need 2.3 million square meters of FPC[9] to generate 12 PJ of energy a year.

The three main fuels that would be displaced in this case are HFO, coal and paraffin. The emissions savings potential of such measures would be vast. It is recommended that the Western Cape provincial government seriously investigate the large scale roll-out of SWH in the F&BI, as this is one of the largest energy consumers within the Western Cape, with a very high portion of energy used for thermal measures. The cost of implementing SWH is far cheaper than CSP and wind power. The devices can be readily installed onto existing factory roofs, thus avoiding the need for costly and lengthy environmental impact assessments. Within the next two years and under certain conditions, the technologies will become financially viable on a purely economic basis alone without the aid of subsidisations.

For COMA, based on its current annual utilisation, the most economic option will be to install a FPC, when the price of coal reaches 1250 R/tonne, or when there are financial incentives that will have the effect of reducing the gap between this figure and the current coal price of R1100 R/tonne.

COMB, which currently has an annual utilisation of 6 months, would only be able to install a viable FPC system when coal prices reach 2500 R/tonne. If the plant were able to make use of the system for 10 months of the year, financial viability could be reached at a coal price of 1250 R/tonne.

For COMC, with an annual utilisation of 4 months, a FPC will not become financially viable, even at a price of 0.90 R/kWh. If the plant could find an alternative use for the heat for an additional 6 months of the year (i.e. annual utilisation of 10 months), the FPC system would be financially viable at an electricity price of 0.65 R/kWh.

Unfortunately, none of the factories presented a case where a FPC system would be able to replace electricity entirely, without any extra system size, as in the case of the COMC plant (this system operates at night and therefore uses thermal storage, which needs an additional collector area to make up for additional heat losses and system inefficiencies). It is recommended that facilities, which have low temperature (<80°C) processes supplied by electrical resistance heaters, should seriously consider implementing FPC systems to cover part of this load.

In conclusion, there is definitely a large potential for solar heat in the Western Cape F&BI. Within the next two years, as electricity prices increase, SWH systems that supplement electrical heating systems with a high annual utilisation will be economically feasible. Systems supplementing coal will become feasible within the next five years.

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Notes

1 A SHS uses solar insolation to generate solar heat, which can then be used for heating, cooling or power generation. The heat transfer fluid (HTF) may not necessarily be water, as is the case with a SWH system.

[2] They state that: "All data in these energy balances was unclassified and therefore to a certain degree inaccurate" (Kowalik and Coetzee, 2005, p. 17).

[3] Inst. Nacional de Engenharia e Tecnologia Industrial (INETI); Bayern Zentrum für Angewandte Energieforschung e.V. (ZAE); Deutsches Zentrum für Luft und Raumfahrt e.V. (DLR); Instituto para la Diversificacion y Ahorro de la Energia (IDAE); Institut Catala d'Energia and Sociedade Portuguesa de Energia Solar (SPES).

[4] This term takes into account both the optical losses and heat losses experienced by a solar collector. The term is temperature dependent.

[5] In European testing procedures, the variable T_i is replaced by the true mean fluid temperature across the absorber. Hence the factor F_R is replaced by F' to compensate for the fact that T_i and T_m are not the same. Data for this project is mostly in the European format. It is possible to convert from one form to another.

[6] The first column of figures in bold font has been used in the Original Scenario Analysis, reflecting current fuel costs. The other costs will be modelled in a future fuel price scenario.

[7] 1 month of operation (730 hours) refers to the utilisation of the plant, whereas the utilisation of SHSs will be dependent on the amount of sunlight hours.

[8] Where one TJ is equivalent to 2.388×10^{-5} Million tonnes of oil equivalent (Mtoe).

[9] This is using the annual output of the FPCs modelled in RETScreen for this project. The average energy collected by a FPC in Cape Town was 1.439 MWh/m^2 per year.

[10]

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