Large-Scale Solar Thermal in South Africa: Status, Barriers and Recommendations

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Abstract

This work analyses large-scale solar thermal (ST) systems in South Africa (SA) to provide insight into the existing market status, case studies, barriers and recommendations. A database of 89 large-scale ST systems (gross collector area > 10 m^2) in SA has been generated and analysed with regards to costs, applications and beneficiary industries. Results show that since 2007 the total annual commissioned collector area was as small as 1 544 m^2 on average. Most systems are used for domestic hot water preparation in residences of educational institutions and change houses in the mining industry. The average system costs are currently 603 EUR/m^2, which is far above the costs achieved in other countries. Using data from a tendering process for a 120 m^2 process heat system in a brewery, 10 proposals were analysed in detail by looking at overall costs, component costs, competitiveness, cost reduction potentials, and overall technical and financial feasibility. The proposed system costs varied by a factor of 2.5, which shows the low maturity of the solar process heat market in SA. The dominating fuel in SA is coal, which currently costs 2 EUR cents per kWh. Current systems can already compete with heat sources like paraffin, diesel, petrol and gas but these are in the minority. Other key barriers are long payback times, the technical complexity of the technology, as well as the lack of awareness and trust in the technology.

Keywords: solar thermal; South Africa; database; case study; solar process heat

Nomenclature

Symbols	Unit	Meaning
C_n	[EUR]	Annual sum of discounted costs
d	[%]	Discount rate
n	[-]	Counting variable for year within service life N
N	[years]	System service life in years
Q_{sol}	[kWh]	Solar heat to processes

Abbreviations	Unit	Meaning
CBC	[-]	Cape Brewing Company
CRSES	[-]	Centre for Renewable and Sustainable Energy Studies
EURc	[EUR]	Euro cents
GHI	[kWh/m^2]	Global horizontal irradiance
IRR	[%]	Internal rate of return
LCOH	[EUR/kWh]	Levelised cost of heat
NPV	[EUR]	Net present value
SA	[-]	South Africa
SPH	[-]	Solar process heat
ST	[-]	Solar thermal
ZAR	[ZAR]	South African Rand

1. Introduction

Renewable energy is becoming more and more important as people become aware of increasing fuel prices and the detrimental effects of fossil fuel emissions on health and the environment. Solar thermal (ST) technology is especially attractive for supplying heat, due to high efficiencies per area and effective energy storage systems. ST technologies are widely used world-wide, contributing an annual heat production of 357 TWh at the end of 2015 according to Weiss et al. [1].

However, most ST technologies are still used only at small scale for domestic hot water production in single family houses. For example, of newly installed systems in Sub-Sahara Africa countries (Mauritius, Mozambique, Namibia, South Africa, Zimbabwe) about 97 % of the systems were smaller scale thermosiphon (or natural circulation) solar water heaters [1]. Large scale applications such as multifamily houses, hotels, hospitals, schools, etc. contribute only 9 % of the world-wide installed capacity and very-large scale applications such as district heating or industrial applications only make up about 1% despite some advantages of larger systems such as lower cost, reduced losses and a more balanced heat demand per m^2.

In South Africa (SA) specifically there seems to be a high potential for larger ST applications. SA is an energy intensive country consuming approximately 122.4 million tons of oil equivalents annually according to BP [2] and at least 1 117 PJ or 44 % of SA´s overall final energy demand is for heat according to SATIM [3]. SA also has one of the best solar resources in the world with global horizontal irradiation (GHI) in SA is typically around 2 000 kWh/(m^2 a) for the major industrial areas compared to central Europe with approximately 1 200 kWh/(m^2 a).

However, only little information on the typical costs, payback, return on investment and existing successful large-scale installations are available to potential clients, installers and decision makers. This paper highlights the key findings of the work by Joubert et al. [4], which sheds a first light on some of these issues by analysing a database on large-scale ST systems in SA, looking at a tender process for a solar process heat (SPH) system at a brewery and evaluating the key barriers to this market. Although the focus of this work is on SA, the findings are considered to be valuable for the field of ST as a whole.

2. Status of Large-scale Solar Water Heating in SA

A database has been set up by Stellenbosch University containing information on large-scale solar thermal systems in Southern Africa commissioned since 2007. The data were collected from an existing database of Blackdot Energy [5], from the Soltrain 1 and 2 projects [6] and data gathered directly from ST companies active in the SA. The database lists 89 ST systems with gross collector areas > 10 m^2 and reflects a total collector area of 13 894 m^2. In the analysis of the database, installations were grouped into various collector area sizes namely: 10 – 50 m^2 (7 % of total area), 50 – 125 m^2 (14 % of total area), 125 – 250 m^2 (21 % of total area), 250 – 500 m^2 (21 % of total area) and larger than 500 m^2 (37 % of total area).

In Figure 1 the total installed area per year since 2007 is shown, with the average installed area per year being only 1 544 m^2. The installations per year seem to vary significantly possibly due to external factors such as the financial crisis in 2008 and the drop of the oil price in 2014.

Domestic hot water preparation for multifamily houses, residences and caring facilities account for about 69 % of the total installed area, followed by 20 % for commercial hot water applications such as staff ablutions at mining change houses. Only 7 % of the total installed area is for process heat and 4 % for cooling.

The costs for 47 of the total 89 systems (61 % of the total gross collector area) which made their financial data available is shown in Figure 2. The data provided is the final cost to client for all components, backup heating, roof support, installation, commissioning and maintenance. It is clear that the costs per collector area tend to decrease for increasing system size. It is also observed that there is a high variation in the costs of systems of the same size due to differences in specifications. Lastly, the weighted average cost per collector area is 603 EUR/m^2. Compared to some systems in Europe which achieved 400 EUR/m^2 [7] already ten years ago, the average specific cost of large-scale ST systems in SA is still very high.

3. CBC Case Study

The Cape Brewing Company (CBC) ST system is one of the latest systems to be added to the large-scale ST database of SA. It is an interesting case study because it is one of the few process heat systems in the country and it provided substantial insight in the local market because of the data provided through the tendering process. The project was initiated by the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University, who approached CBC to investigate the potential for using ST to reduce paraffin boiler fuel consumption

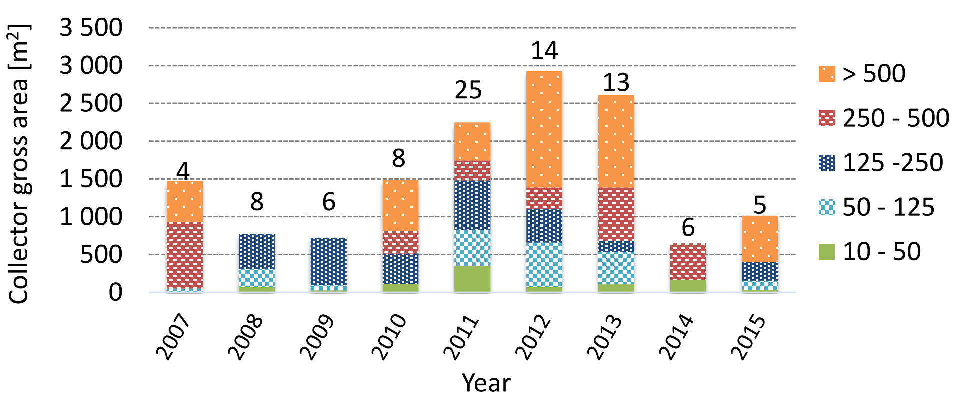


Figure 1: ST collector gross area (> 10 m^2) newly installed in SA since 2007. The total number of installations per year is indicated above the data. Legend unit is m^2 [4].

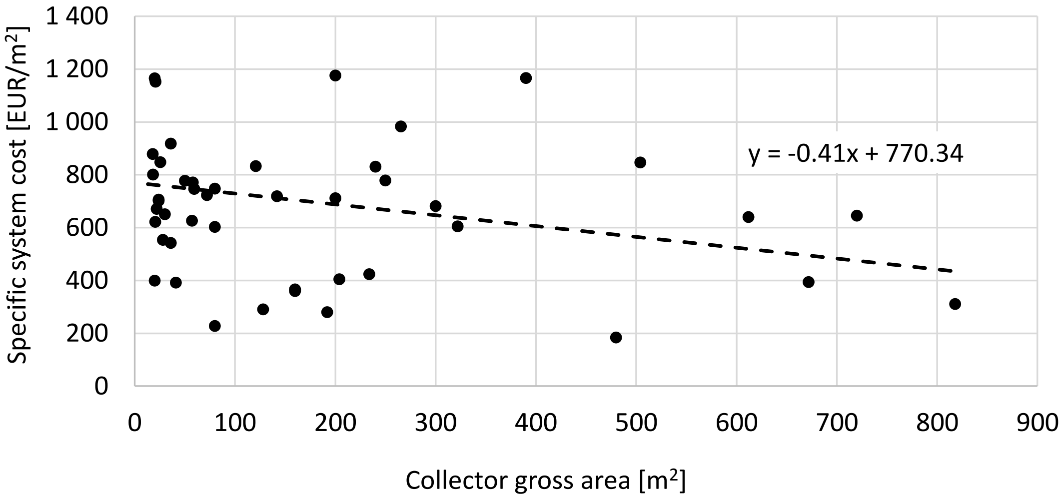
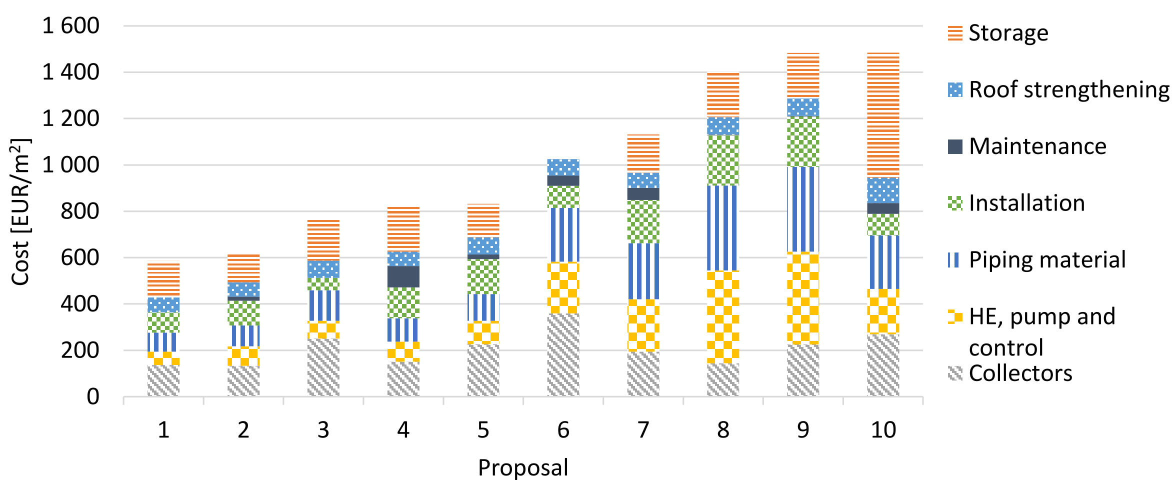


Figure 2: Specific system cost relative to collector area (data from Blackdot Energy [5], Soltrain [6] and personal communication with installers during 2014 - 2015). The exchange rate at the date of installation was used to calculate the system price (9.66 < ZAR/EUR < 15.3 from 2007 to 2015) [4].

and load. A pre-feasibility study indicated that a system of approximately 120 m2 and 10 000 litre storage would be a good investment, especially because of the support from Soltrain 2 through an 11 000 EUR subsidy. Consequently, a request for proposals was sent out, 10 proposals were received in response, all from SA companies. They are compared in Figure 3.

In Figure 3 the cost per m^2, levelised cost of heat (LCOH), internal rate of return (IRR) and payback time is compared for the different proposals. The specific cost includes the sum of all sub-component costs to CBC divided by the gross collector area. The LCOH calculated as in equation (1) and described as the sum of the discounted annual costs (C_n) related to the ST system divided by the discounted annual solar gains ($Q_{sol,n}$) over the 20 year system life (N). The energy gains by the proposed systems were provided in the proposals and verified by independent simulations using the Polysun software. The IRR is calculated as the discount rate d in equation (2), at which the net present value (NPV) of the investment is zero. The IRR calculation takes into



	1	2	3	4	5	6	7	8	9	10
LCOH [EURc/kWh]	7.0	8.4	7.3	8.9	7.9	8.6	15.1	17.9	18.8	13.1
IRR [%]	18.7	15.8	18.2	15.0	16.7	15.5	8.4	6.7	6.2	10.1
Payback [years]	8.6	9.6	8.8	10.0	9.3	9.8	13.5	14.8	15.2	12.5

Figure 3: Proposal comparisons and component breakdown from the CBC tender (using September 2015 exchange rate of ZAR/EUR = 15.3). The table below the graph shows the calculated levelised costs of heat (LCOH), internal rate of return (IRR) and payback period [4].

account the cost of fuel replaced, which was 8 EURc/kWh at the time for paraffin, and expected to increase annually by 10 % based on historical data [8, 9].

$$LCOH = \sum_{n=0}^{N} \frac{C_n}{(1+d)^n} \Bigg/ \sum_{n=1}^{N} \frac{Q_{sol,n}}{(1+d)^n} \quad [\text{EUR / kWh}] \qquad (1)$$

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+d)^n} \quad [ZAR] \qquad (2)$$

Some observations during the tender process were:

- The proposed specific cost vary by a factor of 2.5 between the most affordable and most expensive proposal. This suggests immaturity in the ST market since the tender process was accompanied by an optimal system size, design, on-site walk-though and questions and answers opportunity.
- Inexperienced companies proposed higher costs due to risk coverage, overspecification of components, longer planning times and unfamiliarity with current best practice in large-scale ST.
- Most systems cost more than the average 603 EUR/m^2 as determined from the database. This is due to the need for a customised heat exchanger, stainless steel parts and some special requests from the client to improve the look of the system for tourism purposes.
- Using the cheapest compatible sub-components from all proposals, the minimum price for a working system would be approximately 503 EUR/m^2. This means there seems to be significant potential for cost reduction.
- It is also important to consider the IRR, LCOH and payback in addition to the specific system costs, since these parameters give a more comprehensive overview of the value of the proposal. Based on these indicators, proposal 1, 3 and 5 present the best value for investment.
- After interviewing the best candidates, proposal 5 was selected for realization, because it offered the best combination of technical quality, operational services, and financial return. The final system installed is shown in Figure 4 and Figure 5.

4. Barriers and Recommendations

One of the key barriers to the implementation of ST is the low cost of conventional energy sources. For example, coal, which is the dominant fuel in SA (covering 57 % of the heat demand) has a LCOH between 2.3 and 6.6 EURc/kWh depending on the expected price increase rate. In comparison, the installed CBC system LCOH is 7.9 EURc/kWh. This results in long payback times, which coupled with future uncertainty of the business can prevent companies to commit to adopting the technology. It also means the IRR is quite low. For example, when replacing coal with ST the IRR is calculated to be less than 6 %, which is not a very attractive investment. Solar system cost reduction could be achieved by using local collectors, less stainless steel or if no additional storage is required.

Companies also find it difficult to afford the large initial capital investment associated with ST systems without severely jeopardising their cash flow or alternatively incurring debt. A possible way to overcome this would be through energy purchase

a) **b)**

Figure 4: CBC solar thermal system: a) collector array and b) stratified buffer storage [4].

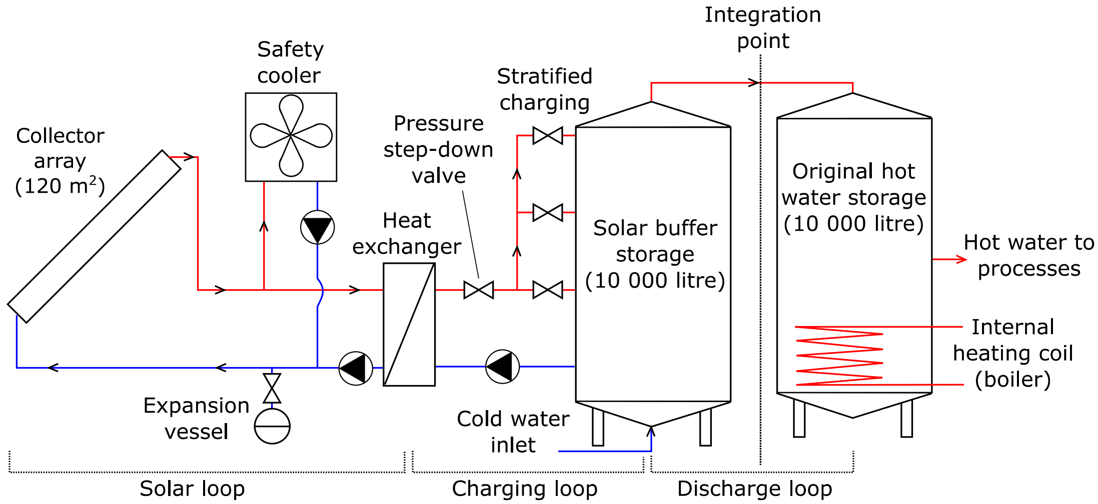


Figure 5: Simplified hydraulic scheme of the CBC solar thermal system with integration into the brewery [4].

agreements (contracting), which is still not very common in ST and in SA. More subsidies would assist to overcome the initial investment, increase awareness and raise experience, but few incentives are available to interested parties. Lastly, companies often consider other competing renewable energy technologies such as photovoltaics, which are relatively simple compared to ST and have seen significant price reduction in recent years.

5. Conclusions

In this work a database of 89 large-scale ST systems and a process heat case study is analyzed providing valuable insight into the existing ST market and its barriers. The results show that there are a number of large-scale ST systems in SA but the overall cost is still high compared to what has been achieved in Europe. This accompanied by the low cost of conventional energy sources in SA provides the foundational barrier for faster adoption of the technology in SA. However, there are low hanging fruit applications such as the case with the CBC process heat system, which proves to be a very attractive investment.

Acknowledgements

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References

[1] Weiss, W, Mauthner, F & Spörk-Dür, M 2016. *Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2014*. Gleisdorf. Available from: http://www.iea-shc.org/solar-heat-worldwide. [9 July 2016].

[2] BP 2014. *Statistical Review of World Energy. June 2014*. Available from: http://www.bp.com/content/dam/bp-country/de_de/PDFs/brochures/BP-statistical-review-of-world-energy-2014-full-report.pdf. [8 January 2016]

[3] SATIM 2013. *Assumptions and Methodologies of the South African TIMES Energy Model*. Energy Research Centre. University of Cape Town. Available from: http://www.erc.uct.ac.za/groups/esap/satim. [21 August 2015].

[4] Joubert, EC, Hess, S & van Niekerk, JL 2016. Large-scale solar water heating in South Africa: Status, barriers and recommendations. *Renewable Energy* 97: 809-822.

[5] Blackdot Energy n.d., *Documenting Commercial Solar Thermal in South Africa*. Available from: http://www.blackdotenergy.co.za/. [15 August 2015].

[6] Soltrain, n.d., *About Soltrain*. Available from: http://sessa.org.za/about-sessa/affiliates/soltrain. [5 January 2016].

[7] GroSol 2007. *GroSol - Studie zu großen Solarwärme-anlagen*. German Solar Association (BSW). Available from: http://www.solarthermietechnologie.de/fileadmin/img/Intranet/AG2/PDF/GROSOL_Studie_BSW_final.pdf. [23 November 2015]

[8] SAPIA 2015. Industry Overview - Fuel Prices Archive. URL: http://www.sapia.org.za/Overview/Old-fuel-prices. [1 October 2015].

[9] DoE-SA n.d. Department of Energy South Africa Petroleum Price Archives. Available from: http://www.energy.gov.za/files/esources/petroleum/petroleum_arch.html. [14 October 2015]