POTENTIAL OF SOLAR THERMAL SYSTEM FOR INDUSTRIAL PROCESS HEAT APPLICATIONS IN THE TROPICS

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ABSTRACT

Many manufacturing and service industries need thermal energy (heat), i.e. hot water, for their processes. Process heat is mostly provided using fossil fuels. As the industry sector consumes a significant share of final energy in most countries, effective utilisation of solar thermal energy for industrial process heat application would contribute to a reduction of fossil energy consumption. In tropical climates, all-year-round availability of solar energy provides a huge potential for industrial heating application. In recent years, the awareness of integrating solar thermal systems into industrial process heat applications in the temperature range of 60 to 150 °C has been increased. However, successful adoption of solar thermal energy into process heat applications depends on technical and economic viability. This paper reviews a wide range of collectors with a thermal efficiency from 60 to 80% for industrial process heat applications. The levelised cost of thermal energy (LCOEth) and the financial viability for installing solar thermal systems in Singapore is also discussed in this article.

Keywords: solar thermal collector; Industrial process heat; tropics; economic analysis, levelised cost of thermal energy.

1. INTRODUCTION

Electricity and gas is the most common resources of energy used for heating applications. These can range from domestic hot water and space heating to a wide diversity of industrial and commercial applications. In general, the requirement of heat for domestic usage is at lower temperature (45 to 60°C) with discrete demand while the industrial heat needs higher temperature (60 to 150°C) with continuous demand [1, [2]. For industrial processes, thermal energy is required for processing a fluid stream (e.g. hot water) and/or, of some reservoirs (e.g. liquid baths). This process heat for low-to-medium temperatures accounts for 33% of global industrial energy consumption [3].
A solar thermal system which converts solar irradiation into heat can be an alternative source of energy for industrial process heating applications. In 2014, about 140 solar thermal plants with a total capacity of 93 MWth have been installed globally for industrial applications [4]. Potential industries for solar thermal system include food, beverage, pharmaceutical, chemical, textile, machinery and pulp and paper industry [5]. Due to a large variety of industrial heating processes, it is critical to know the specific processes for the integration of solar thermal system. For industrial process heat demand up to 150°C, conventional solar collector technology, such as advanced flat plate and evacuated tube collectors, has the potential to provide industrial process heat especially in regions with tropical climates. Collector types, storage capacity, control strategy and system configuration need to be specified to provide the solar heat at the required temperature with the lowest investment cost. Thus, the adoption of solar thermal system for industrial processes requires the consideration of both, technical and economic factors.

From a technical perspective, if industrial process heat demand profile matches with the supply of solar irradiation there is no need for a heat storage. Due to the year-round availability of solar energy in Singapore (the typical annual global irradiation is ~1630 kWh per m2 on horizontal surface) [6], solar thermal systems can provide an attractive alternative to the industrial process heating system in case appropriate building roof space is available.

For the cost-competitiveness of solar thermal systems, it is essential to compare the investment with the long-term fossil fuel price trends. The International Renewable Energy Agency (IRENA) estimates an increased adoption of solar process heat in the order of six-times, if the technology cost continues to decrease based on the technology learning curves and considering fossil fuel prices [7]. There are a number of country studies available analysing the solar process heating economic potential: Germany [8], India [9], the Mediterranean region [10] and South Africa [11].

Even though Singapore has a good potential for the adoption of solar process heat application, no economic analysis for industrial heating applications has yet been published. Thus, the present paper focuses on the economic assessment of the implementation of solar thermal technology in industrial process heat applications in Singapore.

2. SOLAR THERMAL SYSTEM

A solar thermal system consists of collectors, heat storage and discharge system, a hydraulic system and a control system. For the integration of the solar thermal system into the industrial process heat applications, it needs to be ensured that the industrial heating demand is matched either partially or completely by the solar thermal system. This section discusses an exemplary case of a solar thermal system designed for an industrial process heat application.

2.1 Solar Thermal System Design

The integration of a solar thermal system into the industrial process depends on the temperature range of the industrial heat demand. Solar thermal systems are suitable for industries with a high demand of heat during day-time and which is more or less continuous throughout the year [5]. Thus, the integration of solar heat into the industrial process requires for identifying the favourable integration concept from technical and economic viewpoints. The variety of heat demand profiles and process heat applications makes this task challenging. Hence, analysing and designing the integration of solar heat into the industrial process must consider

(i) the time variability of solar heat in intensity and temperature, and
(ii) the necessity of heat storage in order to level out intra-day fluctuation of irradiation.

This paper is based on a solar thermal system, as shown in Figure 1, and an industrial heat demand profile as shown in Figure 2.

As shown in Figure 1, the solar thermal collector absorbs irradiance and converts it into thermal energy, which is transferred to the collector fluid (water). Hot water in the range of 60 - 150 °C from the solar thermal collector is stored in the hot water storage tank from where thermal energy is discharged to the process heat application.

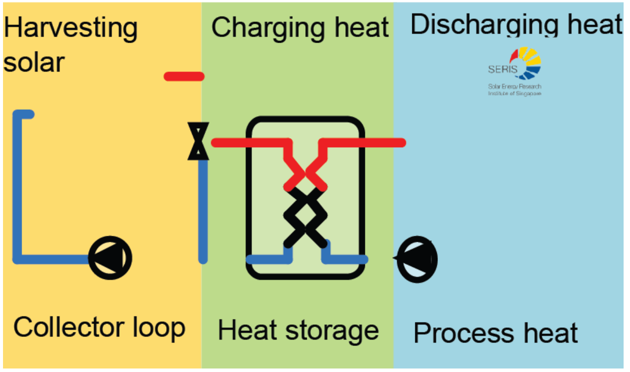

Figure 1: Schematic diagram of a solar thermal system for process heat applications including solar thermal collectors and heat storage. The solar thermal energy harvested by the collectors is stored in a heat storage to level out intra-day fluctuations.

The Figure 2 presents the exemplary heat load demand profile for industrial process in the temperature range of 60 - 100 °C with the following considerations:

(i) Daily heat demand from 7 a.m. to 6 p.m., as shown in Figure 2a.
(ii) Continuous heat demand each week except 4 weeks of a year for maintenance, as shown in Figure 2b.

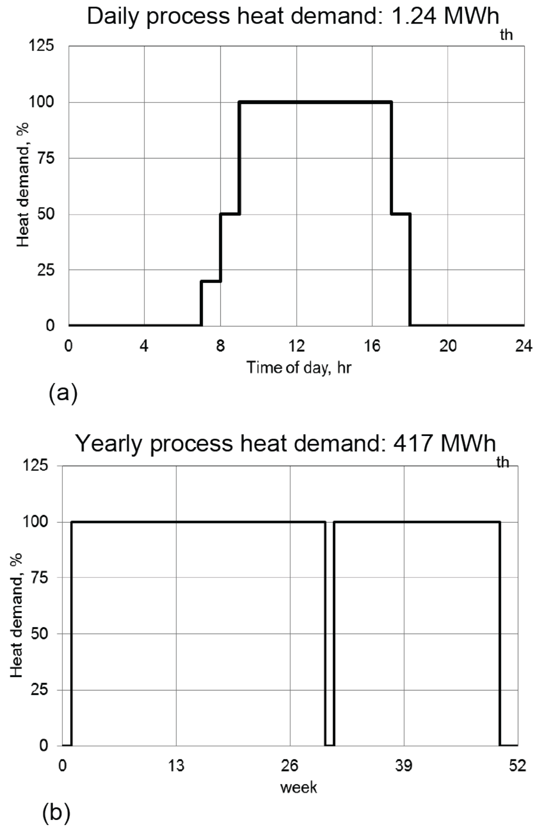

Figure 2: Exemplary heat load demand profile of an industrial process heat application – (a) daily heat demand profile, (b) annual heat demand profile on weekly basis

2.2 System Specification

Solar thermal collectors are the major component of a solar thermal system. The collector efficiency of the radiation-to-heat conversion depends on the collector technology and the operating temperature (mean temperature of the collector fluid) with respect to the ambient temperature and the intensity of irradiation. A variety of collector – flat plate and evacuated tube – types is available in the market for a temperature range of 60 - 150 °C. Collector efficiency varies depending on collector type and collector manufacturer. In this paper, four different collectors (type and manufacturer), presented in Table 1, are considered for the analysis.

In order to integrate solar heat into the industrial process, the most common concept is direct charging and discharging via plate heat exchanger. For heat storage a two-hour buffer storage is considered to level out intra-day irradiation fluctuation. In this paper, a commercial buffer heat storage as specified in Table 2 is considered. The hydraulic system of the solar thermal system consists of piping, fittings and valves, pumps and insulation. The control system includes the sensors, electrical systems, cables and data acquisition and the monitoring system. Costs of these systems are included in the financial analysis in the paper.

Table 1: Solar thermal collector specification according to Solar KEYMARK Certificate [12]

Parameters	***Collector***			
	A	**B**	**C**	**D**
Collector type	Advan-ced flat plate	Evacuated tube		
		Standard	Heat pipe	Heat pipe
Aperture area, m^2	1.05	4.50	2.24	1.42
Efficiency parameters				
η_o	0.759	0.688	0.618	0.574
a, $W/(m^2K)$	0.508	0.583	1.376	1.917
b, $W/(m^2K^2)$	0.007	0.003	0.018	0.012

In order to calculate the financial viability of a solar thermal system, a conventional gas-fuelled heating system is taken as a reference case. The specification of the gas-fuelled heating system is designed to replace the same heating capacity of the specified solar thermal system. A wide range of different industrial gas-fuelled heating systems are available in the market. For this analysis, a well-known industrial gas heater [13] has been considered. Thus, for this financial analysis both heating type systems – solar thermal systems and gas-fuelled heating systems are commercially available.

The gas-fuelled heating system is specified, as presented in Table 2, to meet the same heat demand, as shown in Figure 2. Other components of the gas-fuelled system like heat storage and discharge systems including two-hour buffer time, hydraulic systems and control systems are considered with same specifications as for the solar thermal system.

Table 2: Water buffer heat storage and gas-fuelled heating specifications according to a commercial brand

***Gas-fuelled heating system**:*	***Specifications***
Fuel type	natural gas
Heating capacity (kWh)	117
Tank capacity (m^3)	0.38
Type	commercial
Total units include backup (no.)	2
Water buffer storage:	
Tank capacity (m^3)	0.43
Type	commercial
Total units (no.)	4

2.3 Collector Performance Model

The Solar Collector Energy Output Calculator (ScenoCalc) has been used to evaluate the collector power output at hourly time steps [14]. This was done in order to compare different types of solar collectors under Singapore's climatic conditions. The analysis assumes:

(i) There is a heat load all the time for the solar energy collected,
(ii) The collector is in operation at a constant average temperature and,
(iii) The collector output is only calculated. No other component's performance is simulated.

The program tool is able to evaluate the energy output of both, flat plate collectors and evacuated tube collectors. For the collector performance evaluation, each collector input data – collector aperture area, efficiency parameters related to the aperture area (as outlined in Table 1), incident angle modifiers, was obtained from the Solar Keymark database [12]. For Singapore weather data inputs – solar irradiance, ambient temperature, wind speed, were obtained from the weather station of the Solar Energy Research Institute of Singapore (SERIS) [15]. For this analysis, east orientation and a collector tilt angle of 25° (conservative approach) were considered. For analysing solar thermal collector yield, two cases for the mean fluid temperature increase in the collector field were considered:

(i) 25°C, and
(ii) 50°C

Since the collector performance and the collector costs are widely varied, mean value of the collector performances are considered in the later part of the financial analysis.

3. FINANCIAL MODEL

After the collector power output has been calculated, an Excel-based discounted cash flow model (SERIS in-house) was used to estimate the life cycle cost of thermal energy (LCOEth) for both, the solar thermal system and the gas-fuelled heating system. Figure 3 shows the model flow diagram of the analysis. Sensitivity of the LCOEth cost analysis as well as the cost comparison with respect to the same capacity gas heating system has also been performed in this analysis.

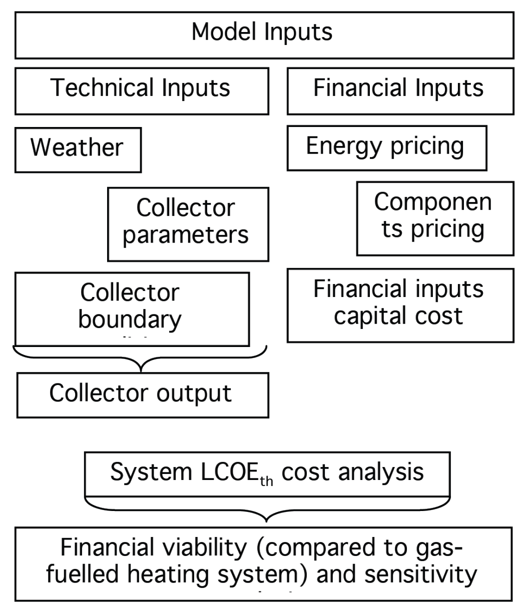

Figure 3: Flow diagram of the financial viability modelling approach

3.1 Methodology/ LCOEth Definition

One of the financial concepts to analyse the cost of a power plant is the levelised cost of energy (LCOE). For this study, the LCOE represents the levelised cost of thermal energy (LCOEth) in cents per kWh of one unit thermal energy production (kWhth). It represents the net present value of the lifetime cost associated with an industrial process heat system divided by the lifetime heat production. The formula used in this analysis is shown in Figure 4.

$$LCOE_{th} = \frac{Lifetime\ cost}{Lifetime\ heat\ production}$$

Figure 4: LCOEth for industrial process heat application

Within the numerator all possible cost items are summed up over the system's lifetime. It includes the up-front investment cost comprising the equity project cost investment and the interest expense during the construction period. The annual operating cost is added which combines the operating and maintenance cost, the insurance cost, the electricity consumption of the pumps and the fuel cost.

In addition, the replacement investments need to be taken into account. Tax payments are added annually including both tax benefits, from having accelerated depreciation and debt financing, and potential tax liabilities. The latter is especially accounted for in case a certain installation replaces an alternative. The benefit of having replaced an alternative, i.e. reduced gas consumption in the case when a solar thermal system replaces a gas-fuelled heating system, the incremental tax liabilities of having less fuel expense within a taxable company is also accounted for. In case external financing has been raised to finance part of the project, annual interest expense and amortisation payment are added. By the end of the operational life, a residual value is either subtracted or added. Subtracted if the system's possible recycling value exceeds the removal obligation and scrap fees, or vice versa.
The denominator includes the system's lifetime heat generation. In case of a solar thermal system, the heat production in the 1st year is calculated by the product of the available irradiance source, the aperture area (m2) and the collector's efficiency. After the first year, the heat output is annually adjusted by the system's degradation rate. For the gas-fuelled alternative, the denominator consists of the customer's heat demand as outlined in section 2.1 including the system degradation rate thereafter.

Both values are discounted by the discount rate (DR) to come up with a net present value figure. The discount rate can either be based on the weighted average cost of capital (WACC) of the company who invests in such a project or upon a required hurdle rate at which such an investment is pursued.

The LCOE concept in general has its limitations which are well documented in various research papers [16-[18]. In order to make the LCOEth more meaningful in this report, a base value has been defined taking the average of four different solar thermal collector specifications combined with conservative underlying assumptions. Following a detailed sensitivity analysis of the underlying parameters, a range of LCOEth outcomes is then presented for both types of heat systems. Furthermore, for the financial viability analysis of solar thermal compared to gas-fuelled heating system, the LCOEth concept is combined with a benefit analysis based on discounted cash flow modelling to calculate net present values (NPV), the discounted payback time and internal rate of returns (IRR).

3.2 Future Gas Price Scenarios

It is assumed that the industrial profile described under section 2.1 consumes gas at bulk B prices (minimum consumption of 50,000 kWh of gas per month). Figure 5 shows the historic progression of gas prices in Singapore [19] in comparison with the high sulphur fuel oil (HSFO) forward price benchmark [20]. The correlation between bulk B gas prices and the HSFO price benchmark during this timeframe was 0.75.

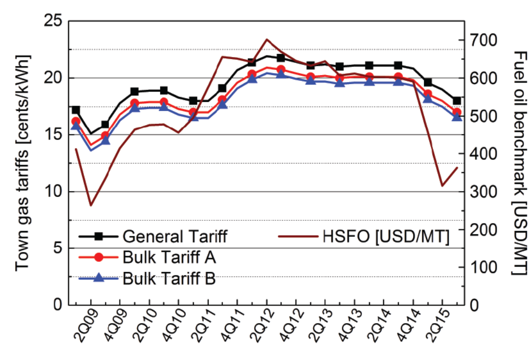

Figure 5: Quarterly historic gas price development in Singapore compared to the HSFO (high-sulphur fuel oil) forward price benchmark

For this analysis it is assumed that the major factor influencing gas prices in the future continues to be the level of oil price. Other factors influencing gas prices in Singapore could be the competitiveness of the sector, supply-demand relationship and transmission constraints. It is also important to note that the sharp drop in oil prices since the 4th quarter 2014 has not yet caused the official gas prices to decrease in a similar dramatic way. Reasons might be that there are floors built into gas resourcing contracts or prices are only re-evaluated after a certain time period. As there might be other unknown factors influencing gas prices apart from the oil price, two sets of scenarios were built. The scenarios presented in Figure 6 show future price developments based on the regression relationship from the historic data set shown in Figure 5. The scenarios depicted in

Figure 7 however show future gas price development in case they change in a 1-1 relationship with the oil price progression (i.e. average HSFO from January to August 2015 is –42% from the average HSFO of 2015).

For each set, three scenarios have been defined for the level of oil prices. The first three years into the future are based on the available HSFO forward price curve for all the scenarios [20]. For this report, the price curve from 3rd of September 2015 was used. Thereafter annual changes were based on future scenarios outlined by the Energy Information Administration U.S. [21] with low growth rate of 0.4% for the minimum scenario, medium growth rate of 1.9% for the most-likely case and 2.8% growth rate for the maximum scenario. Oil prices in 20 years' time, i.e. 2034, would then be around USD 63, 83 and 95 per barrel for the minimum, most-likely and maximum scenario, respectively.

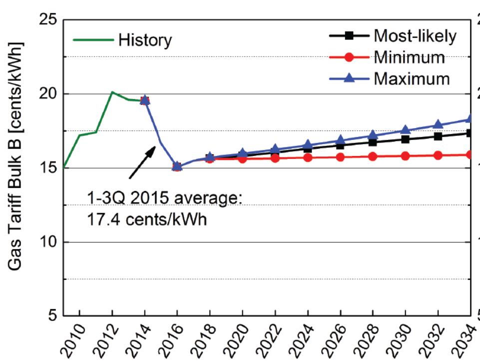

Figure 6: Future gas price scenarios based on historic regression formula, taking into account the 3rd of September HSFO forward price curve until December 2017 and different annual growth rates of oil price development thereafter

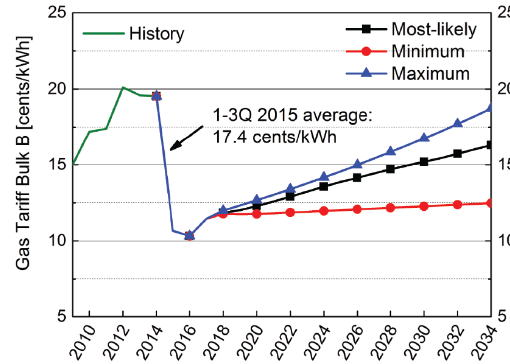

Figure 7: Future gas price scenarios based on 1-1 change to oil price, taking into account the 3rd of September HSFO forward price curve until December 2017 and different annual growth rates of oil price development thereafter

3.3 Input Variables

The financial assumptions are listed in Table 3. The discount rate is based on the weighted average cost of capital (WACC) in nominal terms. It is taken in nominal terms, as inflation is also taken into account at the cost side with 2.5%. This seems to be conservative as the historic ten year average in Singapore was 2.1% [22]. Risk-free rates for Singapore Government Securities (SGS) are used based on August 2015 pricing [23]. The market risk premium used to calculate the equity cost is based on EMA's latest vesting price review for gas fired power plants in Singapore [24]. The beta factor is assumed to be somewhat above general market risk in Singapore; hence a 1.2 value was used. Furthermore, debt financing covering 60% of the capital has been included with a ten year loan at 3% debt premium to the risk-free rate. Regarding depreciation, in general Singapore allows an accelerated depreciation for capital expenditure of three years. For solar and energy efficiency investment there is even a one-year accelerated depreciation scheme [25]. In order to use conservative assumption, the depreciation term for this analysis was aligned with the operational life assumption of 20 years. For the gas-fuelled heating system, it is assumed that the gas heaters will be replaced in year 10, in line with the electricity pump replacements.

Table 3: Financial assumptions for the base value calculation of the gas-fuelled heating system and the solar thermal system

Parameter	Value
20 year risk-free rate (%)	3.2
Market risk premium (%)	6.0
Beta	1.2
Cost of equity (%)	10.4
10 year risk-free rate (%)	2.9
Debt premium (%)	3.0
Cost of debt (%)	5.9
Equity ratio (%)	40
Debt ratio (%)	60
Corporate income tax rate (%)	17
Nominal WACC (%)	7.1
Annual inflation (%)	2.5
Debt financing (years)	10
Depreciation terms (years)	20
Years of operation (years)	20

Based on four available product offers (see Table 1), the mean cost for collector price was SGD 380 per m2. Other system costs include piping, insulation and hydraulic (PIH) components (~30% assumed of total collector price), control system (~10% assumed of collector price), cost of a two-hour water storage system (estimated at ~SGD 19,700) and installation cost. The total investment cost totals ~SGD 300,000 including interest during the construction period (3 months).

The mean value for the collector efficiency is ~59% which represents a specific energy yield of 970 kWh per m2. It was assumed that the system requires ten electricity pumps, each consuming ~2,500 kWh annually and being replaced in year 10 at ~SGD 500 per pump plus inflation.

The electricity price assumption taken are based on industrial price levels, taking into account the most-likely oil price scenario as outlined in section 3.2. Furthermore, it takes into account historic reserve margin regression analysis and assumes a 2.5% annual power demand growth for entire Singapore. This scenario is also based on the 3rd of September 2015 HSFO forward curve and results in an average industrial electricity price of ~15 SGDcents per kWh during 2015, dropping to ~13 SGDcents per kWh in 2016 and gradually recovering thereafter (reaching ~24 SGDcents per kWh within 20 years).

Operating and maintenance and insurance cost have been set in the first year at 1% [26] and 0.5% of total installation cost, respectively, and then annually inflated. An annual degradation rate of 0.8% has been used to account for the humid and challenging climate in Singapore. No residual value has been taken into account.

Table 4: Technical assumptions for the base value of the solar thermal system

Parameter	Value
Collector price (SGD/m^2)	380
Other system cost (SGD/m^2)	310
Total system cost (SGD/m^2)	690
Aperture area (m^2)	430
Collector efficiency (%)	59
Horizontal irradiance (kWh/m^2/year)	1,632
Specific heat yield (kWh/m^2/year)	970
Replacement investment (SGD/year 10)	6,400
Operating & maintenance (SGD, 1st year)	3,000
Insurance cost (% of system cost)	0.5
Pump electricity cost (SGD, 1st year)	3,670
Degradation per annum (%)	0.8
Residual value (SGD)	--

For the gas-fuelled heating system, replacement investment includes the two gas heaters, as their operational life is assumed to be ten years and four electric pumps. Operating and maintenance cost is based on a SGD 0.44 per kWh assumption, converted at a 1.37 USD/SGD exchange rate from EPA's O&M cost indication of USD 0.95 per MMBtu [27]. This accounts for around 1.2% of the initial investment in the first year. The annual gas fuel cost is based on the more conservative most-likely scenario showed in Figure 7. Under this scenario, the gas price would drop from 19.5 SGDcents per kWh in 2014 to 10.7 SGDcents per kWh in the 1st year, 10.3 SGDcent per kWh in 2nd year and then gradually recovering to around 16.3 SGDcents per kWh in year 20. No changes have been made to the degradation, insurance and residual value assumptions used before for the solar thermal system.

Table 5: Technical assumptions for the base value of the gas-fuelled heating system

Parameter	Value
Gas heater price (SGD/per piece)	18,330
Other system cost (SGD)	104,400
Total system cost (SGD)	150,950
Gas heater efficiency (%)	80
Replacement investment (SGD/year 10)	49,480
Operating & maintenance (SGD, 1st year)	1,850
Insurance cost (% of system cost)	0.5
Pump electricity cost (SGD, 1st year)	1,470
Gas fuel cost (SGD, 1st year)	55,570
Degradation per annum (%)	0.8
Residual value (SGD)	--

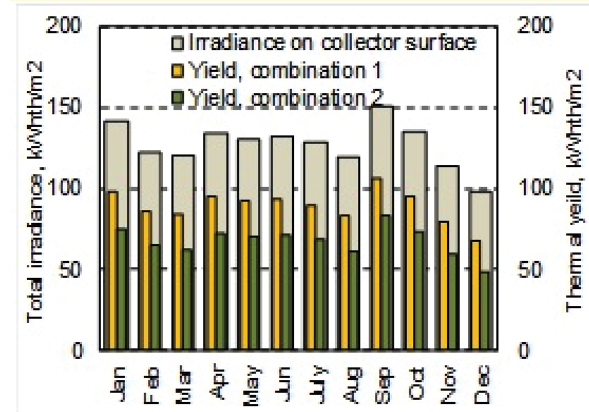

Figure 8: Comparison of two different thermal collector yield performances under Singapore's climatic conditions. An efficient collector (combination 1) combined with a temperature increase in the collector fluid of 25°C (yellow) shows a higher thermal yield compared to the yield of a less efficient collector (combination 2) with a temperature increase in the collector fluid of 50°C (green). To evaluate these collector performances, corresponding data are taken from the similar collector certification conditions.

4. RESULTS AND DISCUSSION

4.1 Collector Performance

As shown in Figure 8, year-round availability of solar irradiation is in the range of about 100 to 150 kWhth/m2 for Singapore. Thus, the solar heat could be utilized for the industrial process heat applications throughout the year. However, the collector efficiency and the operation conditions for untilisation of solar heat are essential to analyse right choice of the solar thermal collector. Based on conservative simulation input values, the annual collector efficiencies vary in the range of 50 to 70%, depending on the collector type and the mean water temperature increase in the collector. Figure 8 shows the collector yield comparison of two different collector types of extreme conditions – (i) combination 1: efficient collector: dT = 25°C and efficient collector, and (ii) combination 2: less efficient collector: dT = 50°C.

4.2 LCOEth of the Systems

Under these base value assumptions discussed under section 3.3 and the application of the formula discussed under section 3.1, the calculated base value LCOEth was determined at ~11 SGDcents per kWh for a solar thermal system and at ~21 SGDcents per kWh for the gas-fuelled heating system.

How sensitive these calculated LCOEth are to changes in underlying financial and technical parameters are shown in Figures 9 to 12. The magnitude of the chosen ranges should reflect realistic positive and negative deviations from the base value described under section 3.3.

Regarding the solar thermal system as shown in Figure 9, the ranges for system price, collector price and collector efficiency, are built upon the minimum and maximum values taken from the different collector data discussed under section 2.2. No positive deviation is taken for the annual irradiance as it is believed that the long-term average (i.e. the P50 value) is already a positive assumption to be based upon. The P99 value, i.e. the annual irradiance value based on long-term historical data with a 99% probability not to be lower than that, is taken as the most conservative. Regarding the heat storage, the ranges were chosen to show what if no water storage tank would have been included (positive change) or what if 4 hours storage buffer time would have been taken instead of the 2 hours used for the base value (negative change). The average PIH components cost is estimated at ~SGD 48,500, around 16% of total system cost. It is based on the assumption to be ~30% of the collector cost, which then was changed +/- 10% for the sensitivity range.

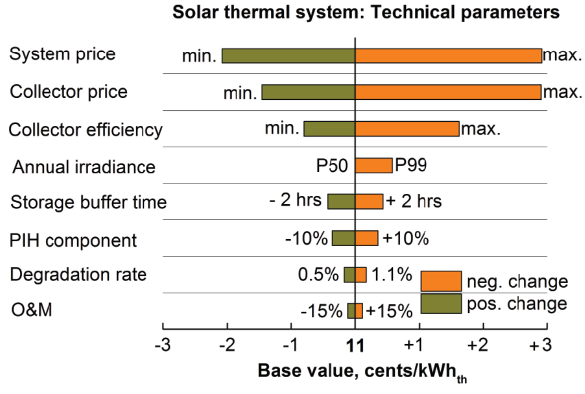

Figure 9: The sensitivities of the base value calculated LCOEth of a solar thermal system towards changes in the underlying technical assumptions. PIH stands for piping, insulation and hydraulic, O&M for operating and maintenance.

For the financial parameters as shown in Figure 10, the changes in the debt interest rate, the cost of equity and the financial leverage cause the discount rate to range from 6 to 9%. The insurance cost ranges between 0.3% and 1.0%.

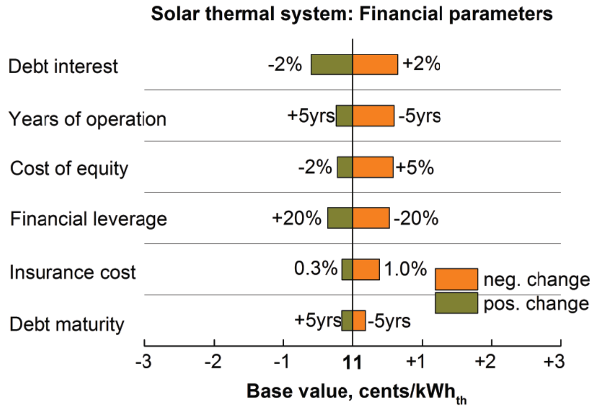

Figure 10: The sensitivities of the base value calculated LCOEth of a solar thermal system towards changes in the underlying financial assumptions

For the gas-fuelled heating system the efficiency range used is 70% to 90%. For the gas fuel cost, the negative range is specified by the minimum future gas price scenario highlighted in Figure 11, while the positive change is based on the maximum future price scenario.

It can be seen that under these sensitivity ranges the LCOEth for both technologies is most sensitive to the system price and system efficiency. In addition, for the gas-fuelled heating system, the LCOEth is also sensitive to underlying future gas price scenarios. Also worth to mention is that due to higher upfront investment cost, the LCOEth of the solar thermal system is more sensitive to changes in underlying financial parameters than is the case for the gas-fuelled heating system.

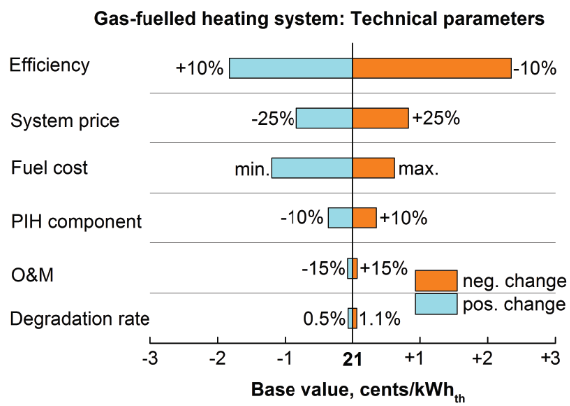

Figure 11: The sensitivities of the base value calculated LCOEth of a gas-fuelled heating system towards changes in the underlying technical assumptions

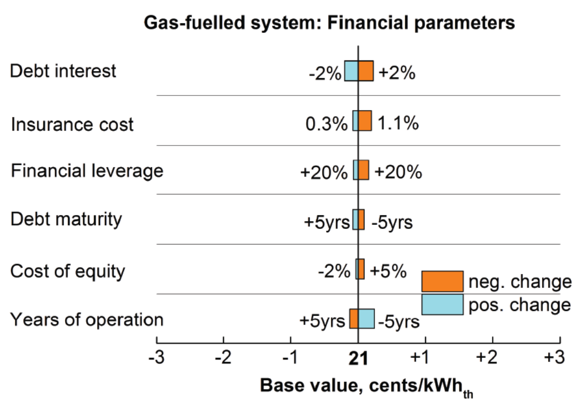

Figure 12: The sensitivities of the base value calculated LCOEth of a gas-fuelled heating system towards changes in the underlying financial assumptions

The possible ranges of the LCOEth of the different technologies caused by a single parameter and based on the maximum sensitivities is 9 to 14 SGDcents per kWh for the solar thermal system and 19 to 23 SGDcents per kWh for the gas-fuelled heating system.

4.3 Financial Viability Analysis

While the initial investment of a solar thermal system is double the one for a gas-fuelled system, the lack of annual gas fuel cost is highly beneficial. The annual operating cost of the gas-fuelled heating system is ~6 to 7 times higher than the one of the solar thermal system, excluding the fact that the gas heaters need to be replaced in year 10. However, the benefit calculation is highly dependent on future gas price scenarios. While the LCOEth calculation of the gas-fuelled system is based on the more conservative one (Fig. 7, i.e. the lower the gas-price, the better the advantage for the gas-fuelled heating system), the financial assessment has been done taking both scenario calculations into account. Table 6 shows calculated net present value (NPV), discounted payback time (DPT), equity internal rate of return (EIRR, i.e. taking debt financing into account) and project internal rate of return (PIRR, i.e. excluding debt financing). The calculated values show that solar thermal can be a financial viable alternative to a gas-fuelled heating system.

Table 6: Financial metrics calculated based on different future gas price scenarios

Gas price scenarios	NPV (SGD)	DPT (yrs)	EIRR (%)	PIRR (%)
Regr. (Fig. 6)				
Maximum	361,500	4	34.2	20.5
Most-likely	351,600	4	33.9	20.4
Minimum	332,600	4	33.5	20.0
1-1 (Fig. 7)				
Maximum	234,300	8	21.1	15.0
Most-likely	208,400	8	20.3	14.4
Minimum	158,600	8	18.4	13.1

The cumulative NPV profile of a solar thermal system replacing a gas-fuelled heating system is shown in Figure 13, based on the most-likely future gas price scenario, taking the 1-1 oil price relationship (Figure 7). It can be seen that the initial equity investment of ~SGD 120,000 can be recouped in year 8. The sensitivity of the cumulative annual NPV progression is shown in case the system price is changed +/- 10% (straight line) or the collector's efficiency is changed by +/- 5% in absolute terms (i.e. 54% for the lower value and 64% for the higher value, dashed line). The discounted pay back varies between 5 to 10 years. Furthermore, the discounted payback period also varies with the debt maturity terms. In case debt financing would be available for 20 years, the discounted payback time could be shortened by 3 years.

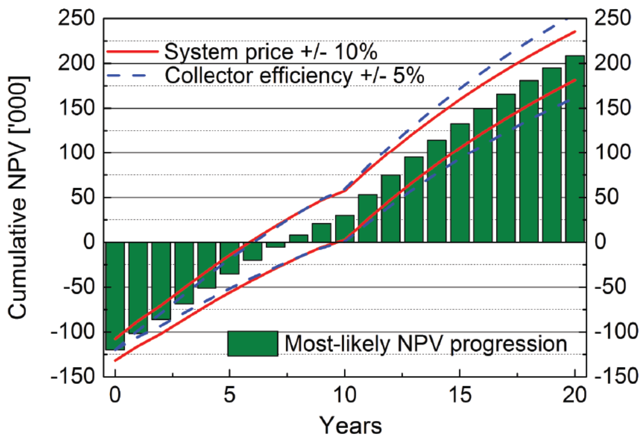

Figure 13: The sensitivities of the base value calculated LCOEth of a gas-fuelled heating system towards changes in the underlying financial assumptions

5. CONCLUSION

Solar thermal heat can provide an attractive alternative energy source for several industries in the tropic countries. The levelised cost of thermal energy generated by a conventional gas fuelled system was determined at 21 SGDcents per kWhth for the example case. Instead the levelised cost of thermal energy generated by a solar thermal system is only 11 SGDcents per kWhth. The discounted payback period of a solar thermal system ranges between 5 and 8 years. Besides the future gas price scenarios, it has been shown that system price and collector efficiency are critical parameters. Hence the design of a solar thermal system is critical for a low payback period. When implementing a solar thermal system, one must ensure (i) an optimal design to effectively utilise the available solar radiation and (ii) integrate it economically into the industrial process heat application.

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