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SOLAR THERMAL FOR DECARBONISING INDUSTRIAL PROCESS HEAT

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Abstract

Demand for heating accounts for 47% of the world energy demand. In South Africa estimates suggest that between 40 and 50% of all final energy needs is for heat. This is more than the amount of energy consumed by the country's transport sector. The demand for heat by industry alone accounts for almost 30% of the total energy demand in the country. Within industry, 66% of energy use is for process heating.

Almost all of the fossil fuels used by industry are for process heat. Despite this, the industrial process heat segment receives little attention in the country's low carbon transition plans. In addition, a significant portion of the electricity consumed by industry is towards process heat. The range varies from 4% to over 60% depending on the industrial subsectors. Given that coal constitutes 90% of the current electricity generation capacity, use of electricity for provision of process heat adds to industry's fossil fuel consumption.

Despite measures to decouple industrial production and energy consumption, there is no doubt that industry's demand for energy will grow if the economy is to grow in line with the Industrial Policy Action Plan and the National Development Plan (NDP). This increase in the demand for energy will increase coal consumption by industry and consequently carbon emissions. Given that almost all of the coal will be used for process heat, the transformation of process heat generation will be a key step towards low carbon industrial development.

Renewable Energy (RE) can play a significant role here. While industry has already started using RE for meeting electricity needs, to date insufficient attention has been paid to the potential of RE in industrial applications. A range of commercially available solar thermal technologies can meet the energy needs for process heat, thereby supporting the decarbonisation of industry. South Africa's abundant solar resource, rising energy prices and carbon emission reduction ambitions in the face of a fossil-dominated energy mix further strengthen the case for solar-based process heat.

In view of the foregoing, this paper will focus on the agri-processing industry to investigate the potential of solar thermal in industrial applications. Agri-processing is one of the largest manufacturing sectors by employment and is key to actualise the macroeconomic objectives of the NDP. In order to stimulate the growth of the sector, the Department of Trade and Industry is focusing on the development and revitalisation of South Africa's agri-processing infrastructure.

About the authors

Manisha is an economist who specialises in the areas of energy, climate change, low carbon development, and resources nexus. She has over 16 years of experience in advisory, research and capacity building in these areas. She has worked in Asia, Africa and Europe where she has advised governments, business, global policy makers, donors, and civil society and delivered high-impact research initiatives. Manisha holds a Masters in Business Economics from the University of Delhi, India, and a BA (Hons) in Economics from St. Stephen’s College, University of Delhi.

Louise is the Programme Manager: Urban Futures, Policy and Futures Unit, WWF-SA. A key focus of her work is the development of an integrated Urban Futures programme that will integrate cities related work in the organisation around the food-energy-water nexus. She has a specific interest in both the impact and potential of renewable energy in the urban context. She holds a BA LLB, an MBA (University of Stellenbosch Business School) and an MPhil in Sustainable Development, all from the University of Stellenbosch.

Contents

Abbreviations and acronyms

CBC	Cape Brewing Company
CPI	Consumer Price Index
CRSES	Centre for Renewable and Sustainable Energy Studies
GHG	Greenhouse gas
HFO	Heavy fuel oil
IPAP	Industrial Policy Action Plan
IRR	Internal rate of return
kWth	Kilowatt thermal
LCOH	Levelised costs of heat
LPG	Liquefied petroleum gas
MWth	Megawatt thermal
NDP	National Development Plan
OPEC	Organization of the Petroleum Exporting Countries
PJ	Petajoule
RE	Renewable energy
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RET	Renewable energy technology
SATIM	South African TIMES model
SMEs	Small and medium enterprises
SOLTRAIN	Southern African Solar Thermal Training and Demonstration Initiative
TIMES	The Integrated Market Allocation–Energy Flow Optimisation Model System

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1. Introduction

South Africa has relatively few solar thermal installations in spite of having some of the highest levels of solar irradiation in the world. In this regard, South Africa's 1 055 MWth of installations are markedly less than Austria's 3 541 MWth and Germany's 12 281 MWth of installations (Mauthner et al., 2015). In addition, South Africa's solar thermal opportunity in industrial applications is significant as industry is one of the largest energy users in South Africa (36–46%) (Energy Research Centre, in Van Vuuren et al., 2016) and half of energy use in South Africa is for heat (Holm, in Van Vuuren et al., 2016). Furthermore, South Africa is highly reliant on fossil fuels, particularly coal, for its energy needs. Solar energy thus provides a key opportunity to decrease this reliance and the attendant risks of price volatility in the instance of oil, diesel and gas, while also reducing greenhouse gas (GHG) emissions.

While industry has already started using renewable energy (RE) for meeting electricity needs, to date insufficient attention has been paid to the potential of RE in industrial applications. Worldwide it is regarded as a niche market (Mauthner et al., 2014), and most of the applications to date have been in sectors such as the sugar and pulp and paper manufacturing sectors, where waste is used to generate heat. However, solar thermal applications are attracting more attention, as evidenced by large-scale plants being installed in the USA and China (Mauthner et al., 2014) in the agri-processing and clothing and textile sectors, respectively. Although this paper looks at the feasibility of solar-based industrial processes in South Africa, it includes a specific focus on the opportunities for solar thermal uptake in agri-processing given that 70% of energy in this industry is for heat (Green Cape, 2017). It is also an industry that requires a significant amount of low temperature heat, which solar thermal energy is able to provide most economically (AEE Intec, 2009a).

The choice of this industry is also influenced by the fact that the agri-processing industry has been highlighted as a key industry for government support in the proposed agri-park programme of the Department of Agriculture, Forestry and Fisheries and the Department of Rural Development and Land Reform. This programme aims to establish an agri-park as an agricultural business hub in each of South Africa's district municipalities. The Industrial Policy Action Plan (IPAP) of the Department of Trade and Industry has also highlighted agri-processing as a key sector to support due to its strong backward linkages to the primary agriculture sector, resulting in significant job creation potential.

The paper demonstrates that there are already a range of commercially available renewable energy technologies (RETs) that can meet the energy needs for process heat, and therefore support decarbonisation of the industry. In addition, market opportunities in the sector open up the possibility of local technology development and manufacturing processes that can unlock new business opportunities in the installation and servicing of solar thermal installations (Green Cape, 2017).

The paper is structured as follow: The next section provides an overview of the potential, characteristics and opportunities of process heat applications, followed by a discussion in section 3 of South Africa's solar resources. Section 4 delves deeper into process heat application, followed in section 5 by a more in-depth discussion on the potential of solar thermal in the agri-processing industry, including a case study. Section 6 addresses the feasibility of solar-based industrial processes in South Africa, section 7 discusses the dividends that flow from an increased penetration of industrial applications, and section 8 provides a snapshot of the present barriers as well as recommendations to overcome them. The paper concludes with a short summation of key arguments to support increased investment in the technology.

2. Process heat applications: Potential, characteristics and opportunities

2.1 Potential

Demand for heating accounts for 47% of the world's total energy demand (IEA, 2016). In South Africa, although the contribution of heat to the total final energy demand is not disaggregated in official statistics, a deconstruction of the end use of energy in the different sectors suggests that almost 41% of the total energy use is towards heating, which takes the form of process heat, space heating and water heating (Table 1). One estimate suggests that half of all final energy need within the country is for heat (Holm, 2015). This is more than the amount of energy consumed by the country's transport sector.

Table 1: Share of heat in total energy demand in different end-user sectors in South Africa, 2015

End-use sector	Share of total energy demand[a] (%)	Energy end use towards process heat, space heating and water heating[b] (%)	Demand for heat as share of total energy demand in the country[c] (%)
Agriculture	3	12	0.4
Commercial	7	21	1.4
Industrial	44	67	29.4
Residential	20	49	9.8
Transport	32	-	-

Sources: [a] and [b] – IEP (2015), [c] – authors computations

The demand for heat by industry (manufacturing and mining) alone accounts for almost 30% of the total energy demand in the country. Within industry, 66% of energy use is on account of process heating (IEP, 2015). In energy-intensive industrial subsectors such as iron and steel and chemicals, process heating accounts for 90% and 88% respectively of total energy consumed (IEP, 2015). In the food and tobacco sector, 79% of the sector's final energy demand is for heat (Lampreia, 2014 in Van Vuuren et al., 2016).

Almost all of the fossil fuels used by industry are on account of process heating. Despite this importance, the industrial process heat segment receives less attention than the electricity and transport sectors in the country's GHG mitigation plans. In addition, a significant portion of the electricity consumed by industry is towards process heating and cooling. The range of this consumption varies from 4% to over 60% depending on the industrial subsectors (Table 2). Given that coal constitutes 90% of the current electricity generation capacity, use of electricity for provision of process heat adds to the fossil fuel energy consumption of industry.

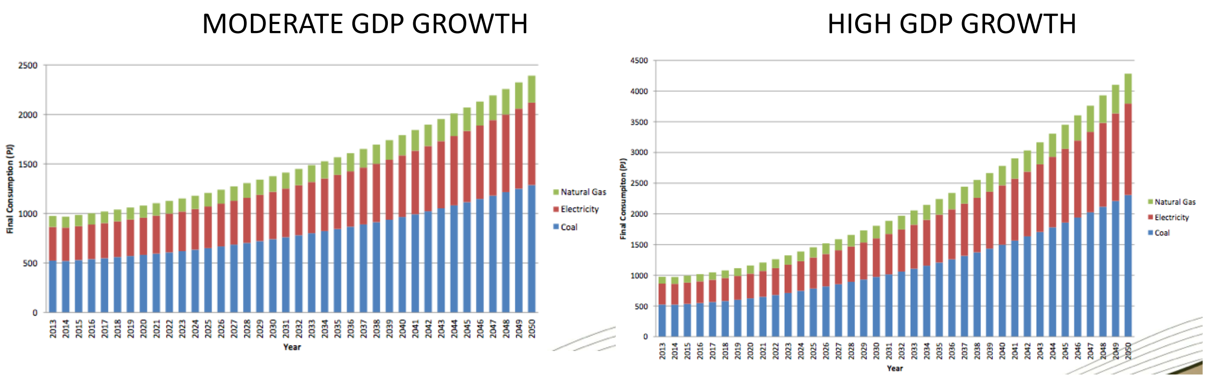
Table 2: Share of electricity used as process heat within the industrial sector

End-use sector	Share of electricity used for process heating within sector (%)
Chemicals	4
Iron and steel	60
Non-ferrous metals	23
Other manufacturing	38
Gold mining	2
Coal mining	3
Platinum mining	2
Other mining	3

Source: IEP (2015)

Despite measures to decouple industrial production and energy consumption, there is no doubt that industry's demand for energy will grow if the economy is to grow (Figure 1) in line with the IPAP and the National Development Plan. This increase in the demand for energy will lead to an increase in the coal consumption by industry (Figure 1), and therefore an increase in GHG emissions. Given that almost all of this coal will be used for process heating, the transformation of process heat generation using RE applications will be a key step towards reducing GHG emissions.

Figure 1: Projected energy consumption for manufacturing in South Africa



Source: DoE (2014)

2.2 Characteristics of demand

A detailed breakdown of industrial heat demand by different temperature ranges is currently not available for the country. However, going by international experience, industrial heating needs can be categorised into three main temperature ranges. The lowest temperature range consists of everything below 80°C, while the medium temperature range is between 80°C and 250°C. The highest range includes everything over 250°C.

According to a study of industrial heating in European countries by Intelligent Energy Europe (2011), about 30% of the total industrial heat demand is required at temperatures below 100°C, 27% at temperatures between 100–400°C and 43% at temperatures over 400°C. From the foregoing it is clear that a significant share of the heat consumed by industry is in the low and medium temperature ranges. The heat requirement below 250°C is particularly high in sectors such as food, wine and beverages, pulp and paper, textiles, plastics and chemical industries, where roughly 60% of the heating requirement is below 250°C. Processes like sterilising, pasteurising, drying, hydrolysing, distillation and evaporation, washing and cleaning, and polymerisation in these sectors do not require high temperatures (IEA and IRENA, 2015) (Table 3).

Table 3: Industrial processes in specific sectors and requisite temperature levels

Industrial sector	Process	Temperature level (°C)
Food and beverages	Drying	30–90
	Washing	60–90
	Pasteurising	60–80
	Boiling	95–105
	Sterilising	60–120
	Heat treatment	40–60
Textile industry	Washing	40–80
	Bleaching	60–100
	Dyeing	70–90
	Drying, degreasing	100–130
	Fixing	160–180
	Pressing	80–100
Chemical industry	Boiling	95–105
	Distilling	110–300
	Various chemical processes	120–180
	Pre-heating water	60–90
	Synthetic rubber	150–200
Paper industry	Cooking and drying	60–80
	Boiler feed water	60–90
	Bleaching	130–150
Metal surface treatment	Treatment, electro-plating, etc.	30–80

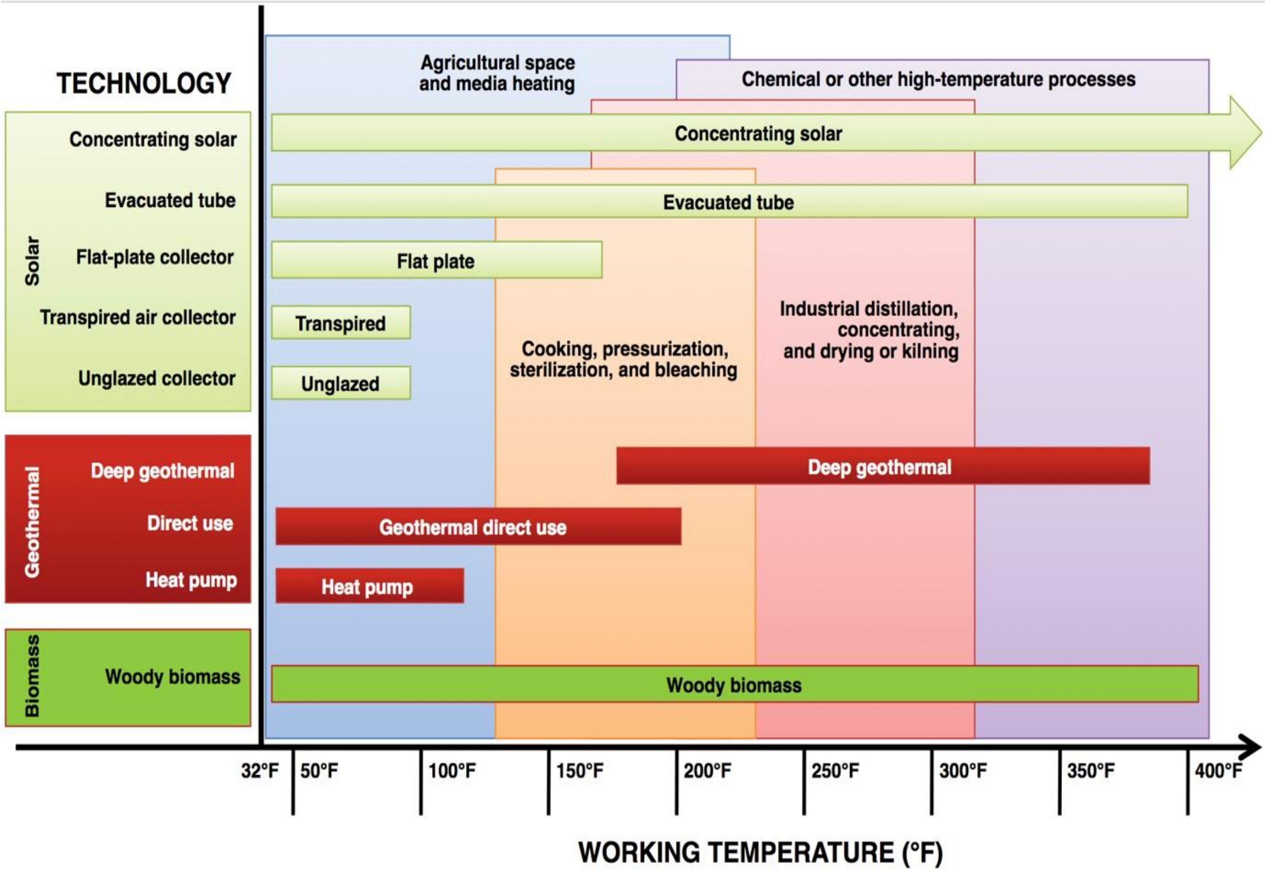
Cork	Drying, cork baking	40–155
Tanning	Water heating for damp processes	165–180
Bricks and blocks	Curing	60–140
Plastic industry	Preparation Distillation Separation Extension Drying Blending	120–140 140–150 200–220 140–160 180–200 120–140
Flour by-products	Sterilising	60–90
Automobile	Paint drying Degreasing	160–220 35–55
All industrial sectors	Pre-heating of boiler feed water Heating of production halls	30–100 30–80

Sources: Compiled from POSHIP (2001), IEA and IRENA (2015) and Van Vuuren et al. (2016)

2.3 Opportunities

Many RETs can easily meet these temperature requirements. Figure 2 provides information on nine different renewable heating and cooling technologies and common applications related to industrial process heat. Even if they cannot support the entire heating load, they can provide pre-heating to supplement the conventional heating process (US EPA, 2017). Since a relatively large amount of energy is required to raise the temperature of water, even a modest amount of pre-heating can support decarbonisation (US EPA, 2017).

Figure 2: Alignment of industrial processes with selected renewable technologies



Source: US EPA (2017)

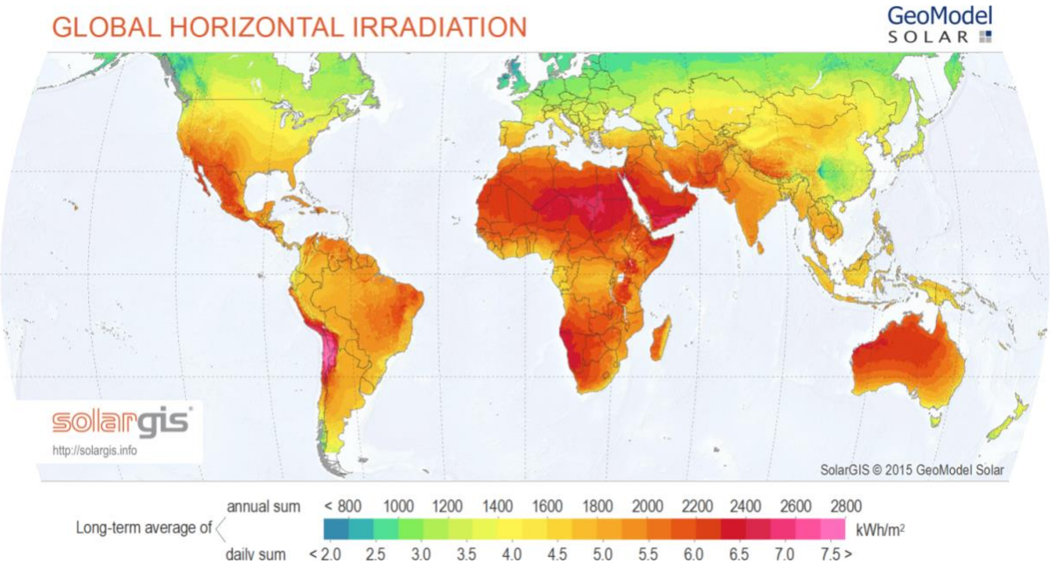
Note: The working temperature ranges shown here are approximate. The exact working temperature requirements for each system will vary based on factors such as system type, size, and location (US EPA).

As seen from Figure 2, almost all industrial process heat demand requires heat in temperature ranges that can be provided by a renewable energy source. Out of these options, solar technologies can achieve all temperature ranges. Solar collectors are capable of meeting temperatures below 250^{o}C and are commercially available today. The highest range includes everything over 250^{o}C and requires concentrated solar power to achieve such temperatures.

3. South Africa's solar resources

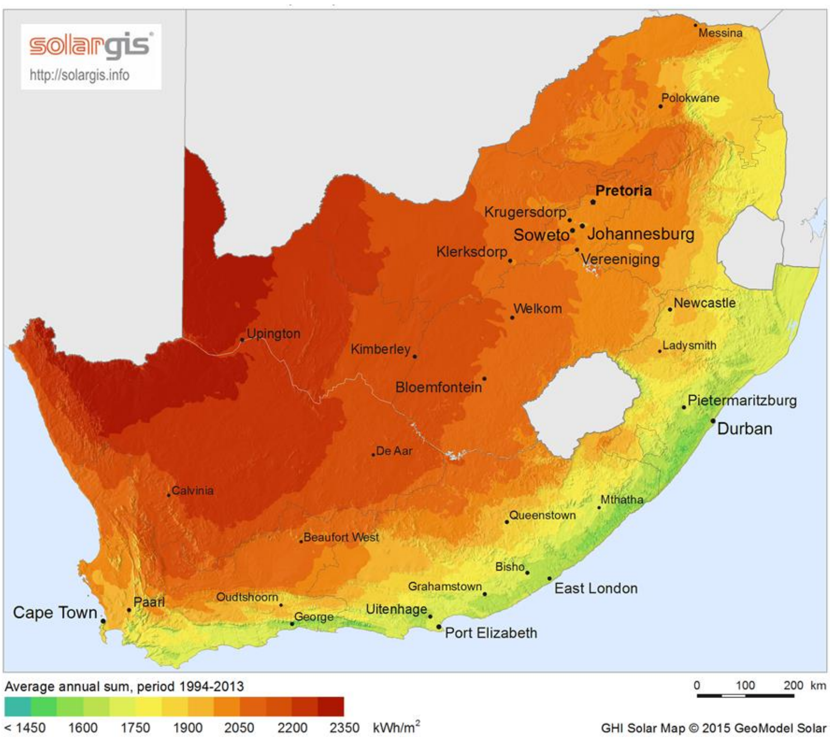
South Africa has some of the highest solar irradiance in the world and experiences some of the highest levels of yearly horizontal solar irradiation globally (Figure 3). The average daily solar radiation in South Africa is between 4.5 and 6.5 kWh/m^2/day (Figure 4) compared to about 3.6 kWh/m^2/day for parts of the USA, and about 2.5 kWh/m^2/day for Europe and the United Kingdom. Clearly, when compared to industrialised countries that are utilising solar thermal technology on a much larger scale, even South Africa's provinces with the lowest potential have higher levels of solar irradiation.

Figure 3: Global horizontal irradiation on the Earth



Source: Solar GIS (2016)

Figure 4: Global horizontal irradiation for South Africa

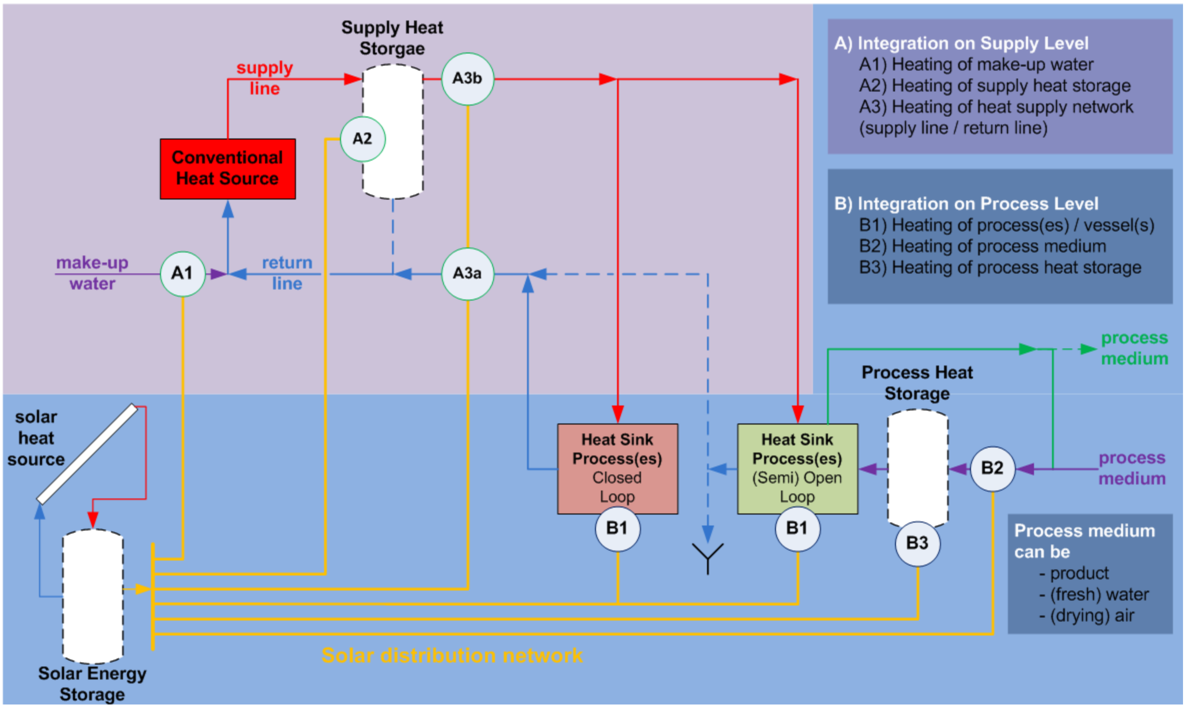


Source: Solar GIS (2016)

4. Technical feasibility of integrating solar thermal

There are different possibilities for the integration of solar heating systems to provide process heat. At the most fundamental level, heat can be provided for industrial systems at either the supply (A) or process (B) level, as shown in Figure 5 for a generic industrial process. At the supply level, integration is possible for heating make-up water, heating supply heat storage and heating a heat supply network. At the process level, the integration is possible by heating the process or its vessel directly, heating the process medium or heating the process heat storage.

Figure 5: Possible integration points for solar process heat

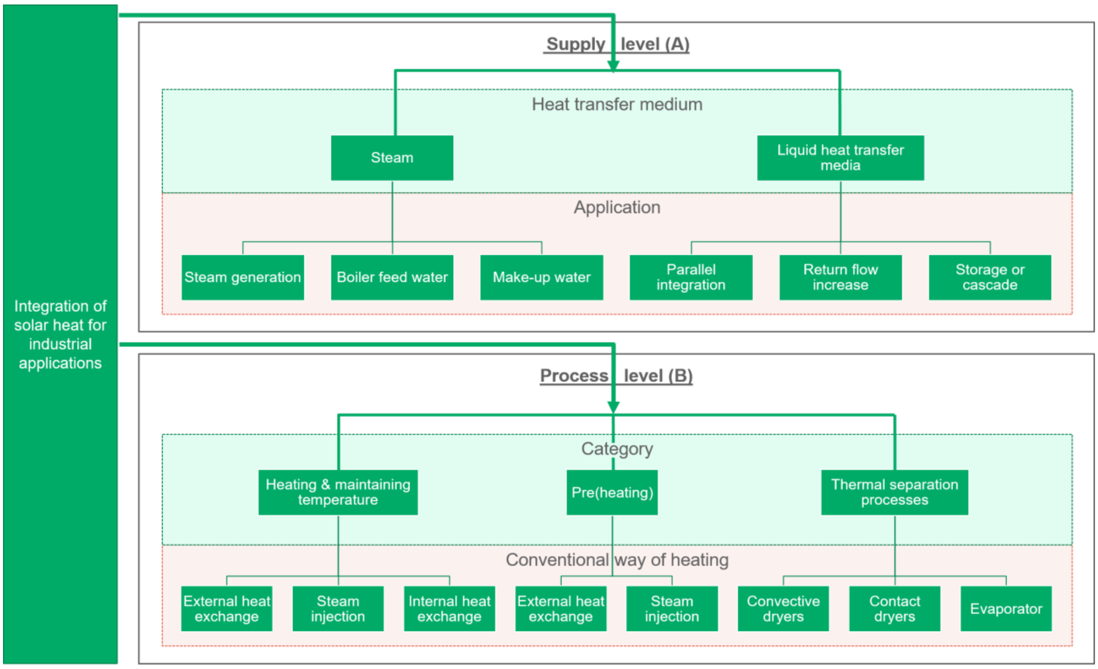


Source: AEE Intec in Hassine et al. (2015, p. 9)

The range of solar heat integration opportunities can be broken down further in two ways. Firstly, at the supply side, the medium that is heated: steam, liquid or air, as highlighted earlier.[1] Secondly, at the process level, it can be divided in terms of whether a process is provided with heat, pre-heating or heat is used to separate substances. The most appropriate integration techniques linked to these integration points are highlighted in Figure 6.

Figure 6: Classification of industrial heat consumers for the integration of solar heat for industrial applications

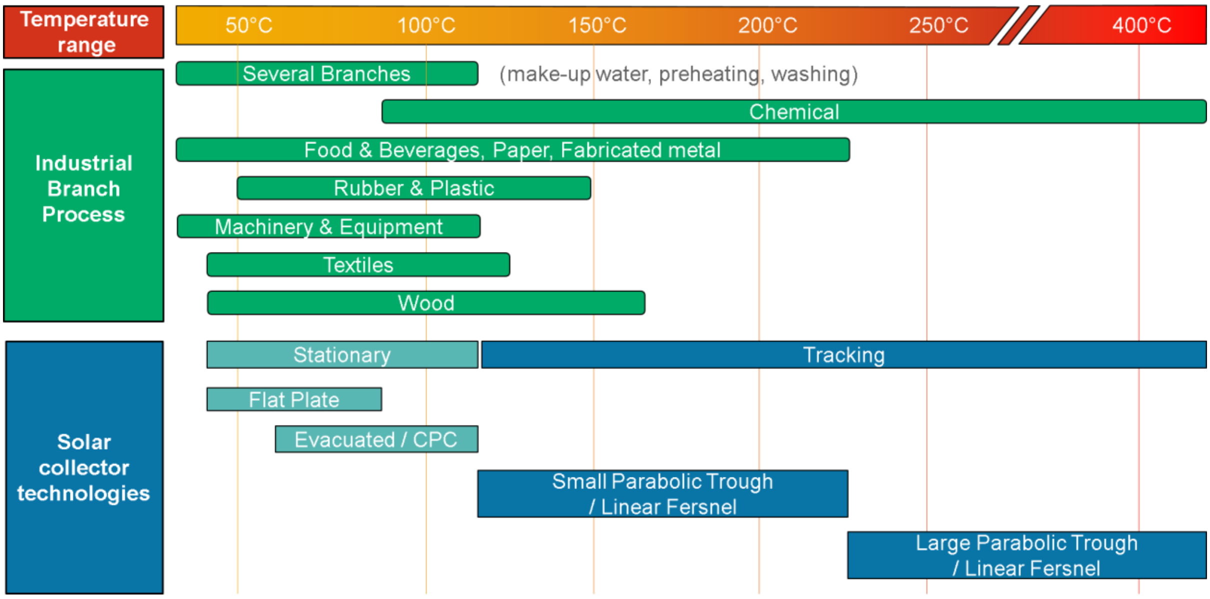
[1] In principle the integration concepts for liquid heat transfer media are also valid for air as heat transfer medium (GreenFoods, 2014).



Sources: Adapted from GreenFoods Efficiency Finder (GreenFoods, 2014); Van Vuuren et al. (2016)

Mapping the available solar thermal technology and the range of processes that require heat can help identify the appropriate solar thermal system. Figure 7 attempts such a mapping and demonstrates the type of solar thermal technology that would be suitable for different kinds of industrial processes.

Figure 7: Stationary and tracking solar collector technologies related to operation temperature and process temperature range in different industrial branches



Source: Adapted from Horta (2015)

Note: CPC = compound parabolic concentrator

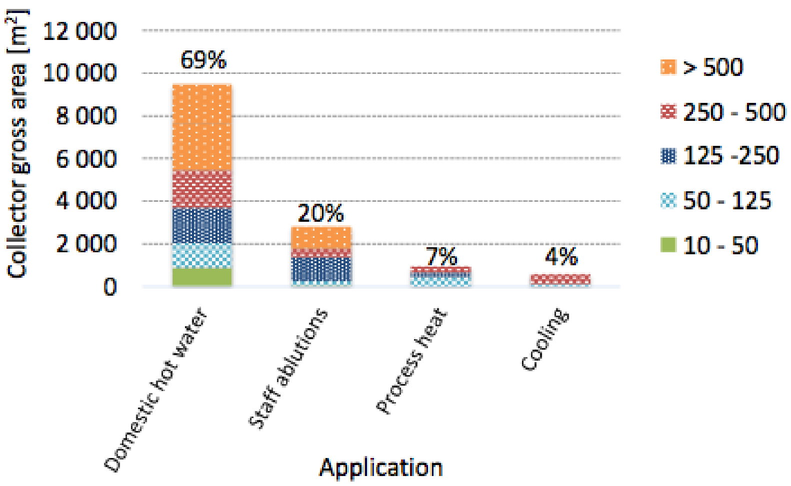
It can be seen that agri-processing and the food and beverages sector (along with sectors such as textiles and machinery and equipment) have comparatively low temperature requirements that allow relatively low efficiency technology (flat plate or evacuated tube collectors) to supply most of the required energy needs. These technologies are non-tracking, do not have moving parts and thus have lower maintenance and installations costs. They are also non-concentrating which is generally a simpler installation and design, again decreasing costs. Clearly, low temperature applications (or pre-heating for higher temperature processes) can be done economically (AEE Intec, 2009 b). There also exists scope for application of small tracking systems in the agro-processing sector although this will likely be at a higher cost than the non-tracking solutions. It is also key to remember that higher temperature processes can still benefit from low cost (fuel free) pre-heating.

5. Solar thermal in the agri-processing sector in South Africa

5.1 Market potential

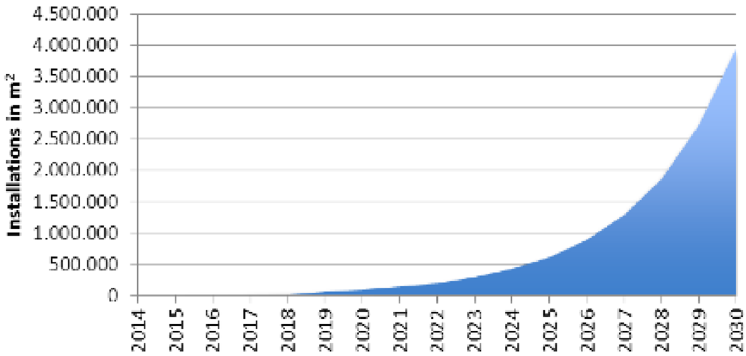
Data on the breakdown of industrial heat demand by different temperature ranges for the many industrial subsectors in the country is sparse. At a very broad level, the potential for solar heat is highlighted by the fact that 40 to 50% of final energy used in the country is for industrial heating. The South African Solar Thermal Technology Road Map estimates that for 2014 there were 213 solar heating and cooling installations of ~50 m^2 for industrial, commercial and multi-family residences, giving a total installed area of 10 635 m^2 (Figures 8). It further notes that separate data for industrial process heat might be determined from boiler statistics. However, these statistics are not currently available. In terms of future potential, the Road Map observes that if the market for industrial, commercial and multi-family residential installations for solar heating and cooling is grown at 45% per year on total installed area from this very low base, the market potential for 2030 can be pegged at 3 957 832 m^2 of installations (Figure 9). The Road Map does not provide these estimates on an industrial subsector basis.

Figure 8: Large-scale solar water heating systems in South Africa per type of application



Source: Joubert, Hess and Niekerk *(2016)*

Figure 9: Total installed area of solar collectors for industrial, commercial and multi-family residential applications, 2014–2030



Source: SOLTRAIN, 2015

However, the potential for process heat in the agro-processing sector can be estimated by using some assumptions. It is estimated that 77–79% of the energy demand in the industrial subsector is for heat (Lampreia, 2014; Energy Research Centre, 2014), with the majority of processes in the sector requiring temperatures well below boiling (thus hot water, rather than steam), which solar thermal is able to supply most economically. Using this together with the energy use of the sector and some basic assumptions, it is possible to estimate the potential for solar thermal in the food and beverages sector. Table 4 provides these estimates.

Table 4: Potential for solar heat in agri-processing

	Total food and beverage energy use (PJ / annum)	**Energy used for heat (PJ / annum)**	**Share can integrate solar thermal economically as estimated by Green Cape**	**Share of energy provided by solar thermal system on average, based on SOLTRAIN guidelines of industrial process heating**	**Solar thermal potential (PJ per annum)**	**Solar thermal potential (GWh per annum)**	**Solar thermal potentialError! Bookmark not defined. (m² installations)**
DOE (2012)	7.4 (2.6 electricity, 4.8 gas)	5.1 (10% of electricity, all gas)	50%	60%	1.53	425	425 000
SATIM (2006)	58.8 (32.4 coal, 15	45.3 (all coal, 9% of	50%	60%	13.59	3 758	3 758 000

	electricity, 1.4 gas, 10 biomass)	electricity, all gas, all biomass)					

Source: Van Vuuren et al. (2016)
Note: PJ = petajoule; SOLTRAIN = Southern African Solar Thermal Training and Demonstration Initiative

Two datasets (SATIM, 2006; DoE, 2012) are available for heat use in the food and beverage sector by energy source. While Green Cape's energy efficiency sector desk suggests that it can be conservatively assumed that solar thermal can economically substitute 50% of this heating need (Van Vuuren et al., 2016), SOLTRAIN (2016) guidelines of industrial process heating in line with existing solar thermal installations in South Africa suggest that the fraction that could be replaced by solar thermal can be assumed to be 60%.[2] Considering an effective solar irradiance of 1 000 kWh per annum (based on a 50% efficiency of collectors and a solar irradiance of 2 000 kWh per annum),[3] the market potential for solar thermal-based process heat in this sector stands at 425 GWh to 3 758 GWh of thermal energy per annum. The significant variation in data sources is attributed to the Department of Energy energy balance allocating no coal to the food and beverage sector. As the use of coal in boilers is widespread, the South African TIMES model (SATIM) data are likely to be closer to the reality for the sector and thus the potential for solar thermal is likely to lie closer to the higher end of the range.

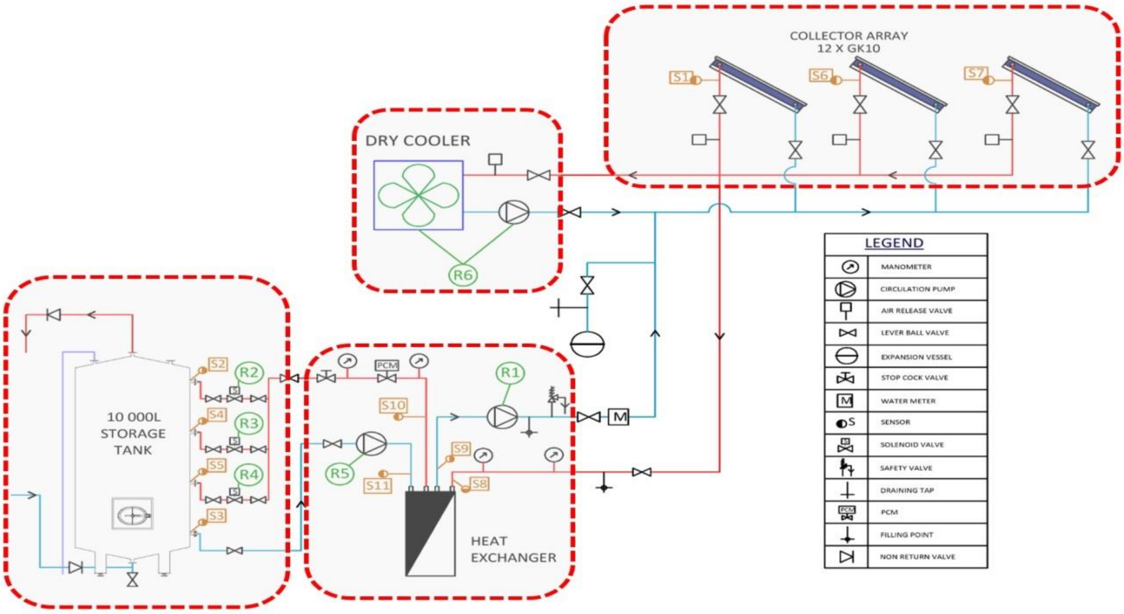
Over and above the heating of water, solar drying also offers much potential. Philibert (2006) highlights solar drying of agricultural products as one of the most promising applications for active solar in the world. In spite of its large drying industry, thermal solar drying as an application in the agri-processing sector is not well developed in South Africa. Partly this is due to South Africa's substantial solar resources, which supports direct solar drying. However, in some areas in South Africa, direct drying is risky due to high humidity and rain when harvesting. As a result, farmers resort to the mechanical drying of food, which is at present highly dependent on the use of fossil fuels or electricity generated by fossil fuels. Replacement with solar drying technologies will impact positively on South Africa's high carbon emissions. In addition, the widespread uptake of the technology will not only reduce food waste, but also throughput to landfill and accompanying emissions. Finally, solar drying technologies respond to retailers' need to decarbonise their value chains and open up new market opportunities for farmers.

5.2 Case study: The Cape Brewing Company

The Cape Brewing Company (CBC), a brewery located on the outskirts of Paarl in the Western Cape, has already demonstrated that solar heat in industrial processes is possible in the beverage sector within South Africa. They installed an 84 kWth solar thermal system in November 2015 that provides process heat for the beer brewing process and hot water for cleaning. The 120 m^2 flat plate collector feeds into a 10 000 litre storage tank for the brewery (Figure 10), which produces 3 million litres of beer annually. With an annual solar yield of 105 600 kWth, the project was tendered to decrease fuel costs by at least 50%. As backup, the existing paraffin boiler is used to ensure security of supply. The system uses a control methodology that allows remote monitoring of the system, which in turn facilitates some preventative maintenance by allowing for the identification of problems before they would otherwise become evident (E3 Energy, 2016).

[2] SOLTRAIN is a programme funded by the Austrian Development Agency and OPEC Fund for International Development to encourage sustainable energy uptake with a focus on solar thermal applications in Lesotho, Namibia, Mozambique, South Africa and Zimbabwe.
[3] For reference, Stellenbosch's annual tilted irradiance is approximately 2 148 kWh per m^2 per annum.

Figure 10: Diagram of CBC installation



Source: E3 Energy (2016)

As noted, the project went to tender with the aim of decreasing fuel costs by at least 50%. The winning bid had a payback period of six years and went beyond achieving the 50% limit by further optimising their system. While the panels were imported from Austria, the storage was locally manufactured. This project was supported by SOLTRAIN and is the largest within the SOLTRAIN Western Cape flagship district (SOLTRAIN, 2015; E3 Energy, 2016). This support was critical as it allocated resources to enable the company to receive technical support in the writing of the tender documents and in the evaluation of their applicability. This was done by the Centre for Renewable and Sustainable Energy Studies (CRSES) at the University of Stellenbosch. The support and expertise of CRSES was critical to ensure both the financial and technical feasibility of the installed system (discussed in more depth in section 6).

6. Feasibility of solar-based industrial process heat in South Africa

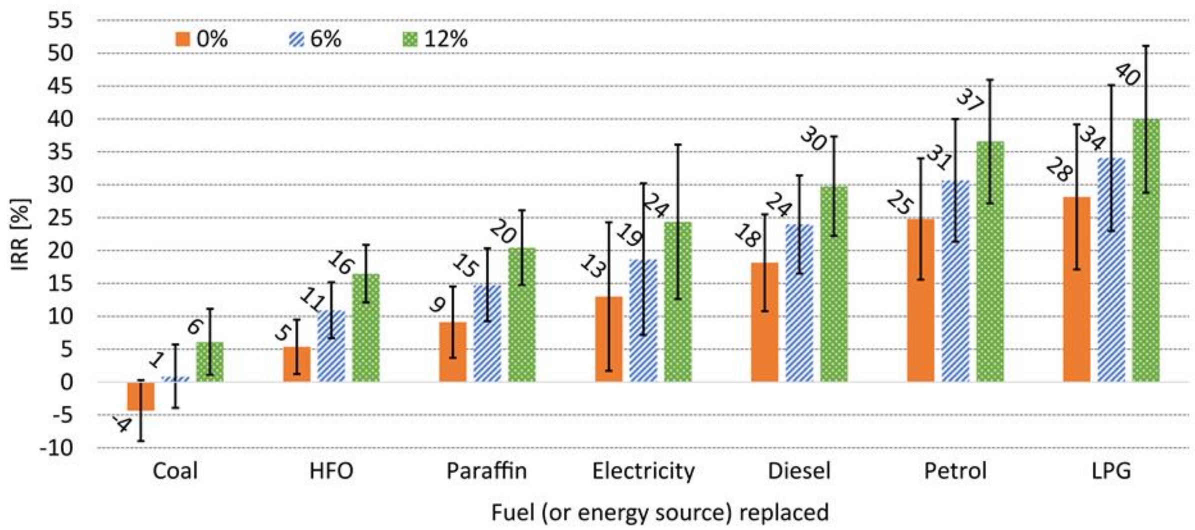
The costs of solar heat for industrial process heat strongly depend on the type of technology, process temperature level, system design and complexity, project size, and specific regional circumstances, such as the level of solar radiation of the site. Therefore, it is not possible to assess the financial feasibility of solar-based industrial process heat for industry as a whole or even an industrial subsector.

In general, the financial feasibility of implementing solar heating would depend on the cost of the installation and the price of the fuel that is replaced. Figures 11 and 12 highlight the internal rate of return (IRR) and payback period, respectively, for a 0%, 6% and 12% increase in price for the replacement of a range of fuels. The results indicate that while substituting coal with solar thermal energy at present is not financially feasible, it is at least worth exploring for all the other fuels considered, specifically heavy fuel oil (HFO), paraffin, electricity, diesel, petrol and liquefied petroleum gas (LPG). This is evident with the IRR above 10% for all fuels (except coal) when a conservative 6% price rise is considered (Figure 11). Furthermore, payback periods are in the range of five years for paraffin, electricity, diesel, petrol and LPG (Figure 12).

In terms of fuel substitution, solar thermal avoids not only the costs of fuels but also the inherent volatility of the fuel prices. This may aid in long-term planning as the solar thermal yield and maintenance costs are relatively constant, while the oil price and its related fuels (HFO, paraffin, diesel, petrol and LPG) are inherently volatile. It is worth noting that the case for substituting these fuels (including coal) could improve when a carbon tax is implemented.

It is also worth noting that the return and payback period for the same system varies according to application. For example, while the average payback period for electricity systems with no increase in electricity price is 10 years, there are instances[4] where payback will be less than five years, even with no electricity price increases.

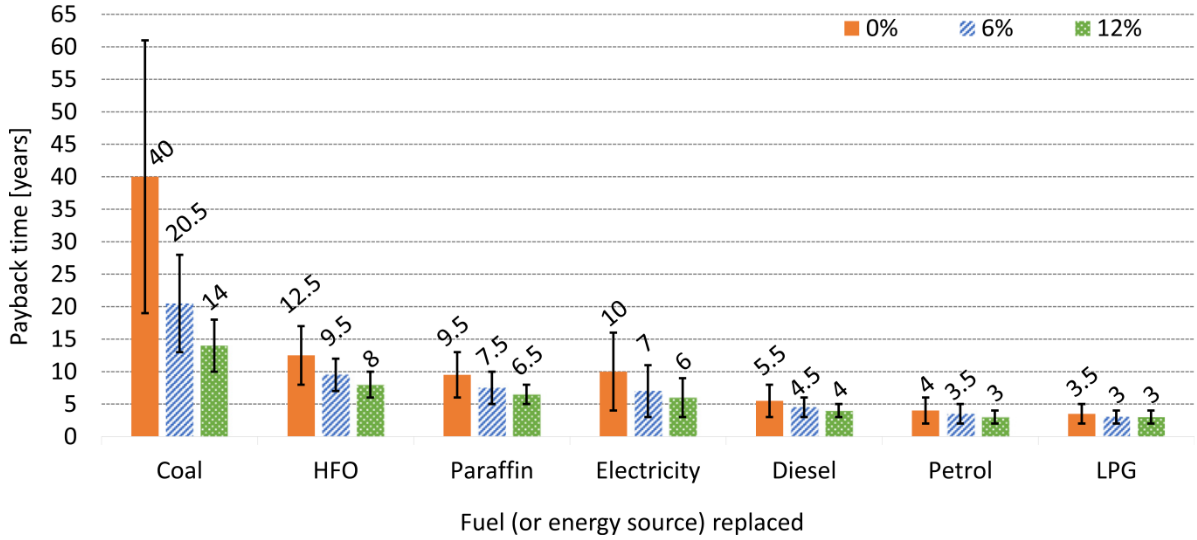
Figure 11: IRR for a current large-scale system with costs of 603 EUR/m² service life of 20 years replacing different conventional fuels



Source: Joubert et al. (2016, p. 820)

Figure 12: Payback periods of current large-scale solar thermal system when substituting conventional energy source

[4] Shown by the error bars on the graphs.



Source: Joubert et al. (2016, p. 820)

7. Dividends from solar-based process heat

7.1 Environmental dividend

South Africa is among the top 20 countries globally when measured by the absolute level of GHG emissions (Gulati et al., 2016). The country's per capita emissions of 9.18 tonnes of CO_2 exceed the world average of 4.49 tonnes of CO_2 per capita and are higher than those of China, Brazil and India (Satgar, 2014). South Africa is committed to reducing its carbon emissions by 34% and to ensure a 42% deviation below its 'business as usual' emissions growth trajectory by 2020 and 2025, respectively (Gulati et al., 2016).[5] Additionally, the country is committed to an absolute decline in GHG emissions from 2036 onwards.

The single biggest reason for this is the country's high reliance on fossil fuels due to an abundance of coal. Coal accounts for 77% of the total primary energy mix and 90% of the electricity generation capacity in the country. It is not surprising, then, that the energy sector is the single largest source of GHG emissions and accounts for about 89% of the country's total emissions. Clearly, the solution to the country's GHG emissions lies in the energy mix and necessitates a shift to low-carbon energy sources. While measures such as energy efficiency need to be considered, these are unlikely to deliver emissions reduction at scale.

Given that South African industry is the biggest energy user (see Table 1) and is energy intensive (see Box 1), interventions that specifically target the energy sources used by industry are likely to be as effective as changing the electricity generation mix in the country. Coal and coal-based electricity are the dominant sources of process heat for industries. Replacing them with RE will reduce GHG emissions. The quantum of emissions reduction will depend on the pace with which solar-based industrial process heat is rolled out in the country. Based on the market potential estimated by the

[5] This commitment is conditional on finance, technology and capacity-building support from the international community.

Solar Thermal Road Map, the environmental dividend could be estimated at savings of almost 3 400[6] million kg of CO_2e.

Box 1: Energy intensity of South African industry

Historically, South African industry's competitiveness has been built on low electricity tariffs derived from the abundance of coal. South Africa has the fourth largest deposits of coal globally.

Other factors have also had a bearing on the level of and trend in electricity tariffs. A discussion on these is beyond the scope of this study. Suffice it to say that South Africa's electricity prices have been low by international standards. This is borne out by the fact that in 2006, the industrial electricity tariff in South Africa was the lowest in the world (Sharan et al, 2016). The country's industrial development policy has used the low electricity tariffs as a tool to attract investments. The marketing of investment opportunities highlights the availability of electricity at 'very favourable rates' as one of the attractions (CDC, 2004 in Winkler and Marquand, 2009). This has two broad consequences. First, South Africa became an attractive destination for investment in energy-intensive industries such as aluminium smelters and, second, the manufacturing industry in general became electricity-intensive.

The extent of emissions reduction possible specifically for the agri-processing sector is shown in Table 5. Interestingly, there is a large difference in potential carbon savings, most notably due to the inclusion of coal (which is a particularly carbon-intense fuel) in the food and beverages estimate of the SATIM model, and its exclusion from the Department of Energy dataset. The emissions savings potential for solar thermal is then in the broad range of 110 000–940 000 tonnes of CO_2e from the uptake of solar thermal. As the SATIM model is more detailed and more consistent with known practice (Van Vuuren et al., 2016), the real savings potential is expected to be in the upper end of this range.

Table 5: Potential for solar heat in agri-processing

Data source	Potential energy savings per annum	CO_2e savings (tonnes/annum)			
		Coal	Electricity*	Gas**	Total
DOE (2012)	0.08 PJ electricity 1.45 PJ gas	-	23 117	87 806	**110 922**
SATIM (2006)	9.72 PJ coal 0.45 PJ electricity 0.42 PJ gas	783 871	133 326	25 359	**942 556**

[6] 3 957 832 * 867 *0.99 where 867 kWh is the specific solar yield per m^2 for South Africa as per the International Energy Agency and the carbon intensity of one unit (kWh) of electricity for the country is 0.99 kg CO_2.

Data source	Potential energy savings per annum	CO_2e savings (tonnes/annum)			
		Coal	Electricity*	Gas**	Total
	3 PJ biomass#				

Source: Van Vuuren et al. (2016)

Notes: * Emissions factor for 1 kWh of electricity 1.06 kg CO_2e based on Ecoinvent database South African energy mix; ** Emission factor of 0.0605 CO_2e per GJ (3 significant figures); # Only emissions from fossil fuels considered so biomass excluded from emissions; PJ = petajoule.

Another dimension to the environmental dividend comes from South Africa's priority to re-industrialise (discussed later). It is important that this industrial revival is done in a sustainable way. Industry needs to be encouraged to leapfrog to climate-friendly technologies if it is to avoid locking itself into long-lasting, inefficient and polluting technologies for decades to come (UNIDO, 2011). South African industry has already done so in the past when coal underpinned the country's industrial growth. The resulting carbon footprint is evident from the current level of emissions and the urgent need to reduce them.

7.2 Economic and social dividends

7.2.1 Energy security

South Africa's current energy security crises can be understood through the electricity supply crisis. Although emergencies in supply were first declared in 2008, a shortage of electricity supply was already experienced in 2005 and has become chronic since early 2014. Although the situation has now stabilised, this is due more to lack of demand than to the addition of supply capacity. This shortage has necessitated limiting electricity supply to large customers to maintain adequate reserve, as well as a period of national load shedding. The reserve margin reduced from 40% in the mid-1990s to a point where the supply–demand balance was very tight and the reserve margin dipped to 1%. Solar-based process heat will reduce the overall demand for electricity used by industry, thereby helping to reduce electricity demand, avoiding power outages and enhancing energy security. It will also replace fossil fuels, thereby diversifying the country's energy mix. Solar thermal specifically offers the added benefit of inherent thermal storage with up to 12 hours' supply capacity (DoE, 2015), offering greater flexibility in terms of when electricity is supplied.

7.2.2 Economic savings

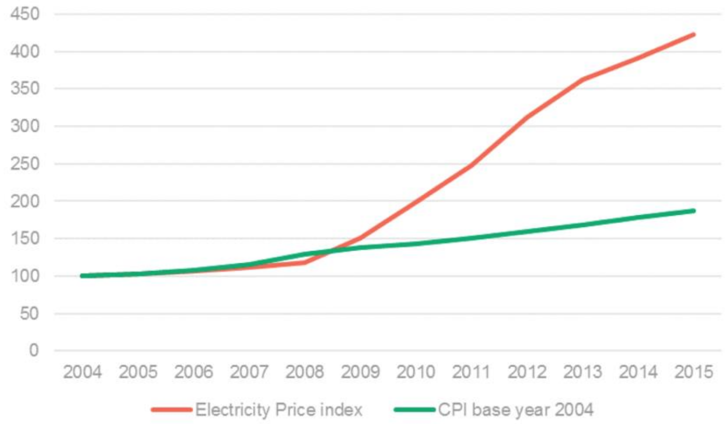
The use of solar thermal for heat can reduce the macroeconomic risks linked to the fluctuation of energy prices and the security of energy supply. The economic value of this would be significant, but cannot be quantified without knowing the future prices and quantities of fuel that it replaces. A sense of the magnitude of savings can be gauged from the fact that using concentrated solar thermal to cater to peak demand will result in savings of approximately R3.6 billion per annum (Sager et al., 2015).[7]

[7] This computation is not referenced to a specific year and is generic.

7.2.3 Affordable energy

Besides the shortage of electricity, South Africa is also facing electricity price hikes. The price of electricity has increased over 400% over the last decade in unpredictable and often unexpected increments, and is significantly greater than inflation (Van Vuuren et al., 2016) (Figure 14). Although the extent of price rises has moderated, prices are expected to rise further, as Eskom needs to maintain its aging portfolio of plants and fund new capacity to ensure sufficient future supply. Some estimates suggest the tripling of the real price of electricity by the time adequate new electricity generation capacity is brought on line between 2017 and 2020 (Van Vuuren et al., 2016). Solar thermal-based process heat will help ring-fence future electricity price hikes, thereby ensuring affordable energy for industry.

Figure 14: Electricity Price Index and Consumer Price Index (2004 base year)



Source: Green Cape computations using National Energy Regulator-approved average tariff adjustment as per published tariff book indexed to base year 2004 (Eskom, 2016) and historical Consumer Price Index (CPI) (StatsSA, 2016) in Van Vuuren et al. (2016)

7.2.4 Manufacturing and jobs

Solar thermal can support industrialisation and boost domestic manufacturing as well as job creation, in line with the government's priorities, in different ways.

First, South Africa is seeking the long-term intensification of the industrialisation process (dti, 2007). Additionally, there is a view that the country needs to 're-industrialise' (DEA, 2016). This view seeks to rebuild the country's manufacturing base to account for 30% of GDP as opposed to the current 15% (DEA, 2016). This industrialisation or re-industrialisation is key to meeting the core challenge of mass joblessness that the country currently faces. A stable energy supply will be crucial for this industrial intensification.

A power supply crisis poses the biggest obstacle to this intensification. The power outages that started in 2007/08 are threatening the country's productivity, economic performance and competitiveness (Mannak, 2015). Lack of reliable power supply – where general overcapacity and low-priced reliable supply has evolved into undercapacity and unreliable supply of coal, electricity and liquid fuels, with coal and electricity prices rising significantly – has been one of the key factors affecting industry at all levels, from mines to small manufacturing units. Unstable electricity supply is said to be costing the private sector up to R89 billion (US$7.2 billion) every month in lost production, revenue and wastage (Mannak, 2015). By substituting electricity as the source of energy for process heat, solar thermal can increase the availability and reliability of energy supply for the growth of the country's manufacturing sector.

Second, the carbon tax proposed to be levied by the government to contend with the challenge of climate change and facilitate the low carbon transition will increase input costs for carbon-intensive materials (such as cement and steel) and tax industry on direct emissions from its manufacturing processes. The rise in the price of electricity resulting from the high reliance on coal for electricity generation in the country is likely to significantly impact manufacturing, although the manufacturing sector is too diverse to make any simplified conclusions about its vulnerability to rising electricity prices. Nevertheless, as noted, the manufacturing sector is vulnerable to electricity costs and affordable electricity will therefore be key to the growth of the sector. An alternative source of energy such as solar thermal that has zero variable costs would greatly benefit this sector.

Third, the industrial use of solar thermal for process heat could add to the building of a competitive supply chain for renewable energy technologies, started by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). The REIPPPP has a minimum participation requirement for local content (as a percentage of project value) wherein a percentage of the project spend is retained for local suppliers, encouraging the growth of the local industry. The minimum thresholds and targets for local content have been set consistently higher with each successive bid window. The use of solar thermal for industrial heat will provide an additional market to this supply chain.

Additionally, solar thermal would also provide a market for the country's well-established manufacturing base of traditional industries. Many components of solar thermal systems, such as the tanks, can easily be manufactured by local companies. Given that many traditional industries are struggling, this could be an opportunity to boost these industries.

8. Barriers to overcome and recommendations

Despite the technical potential and the potential economic benefits of using solar heat in industry, actual deployment levels remain quite low. Scaling up deployment as a mitigation measure for emissions requirement will require addressing various barriers. These barriers can be grouped into four categories.

8.1 Data barriers

Data on the contribution of heat to the total final energy are inadequate. The collection and reporting of energy-related statistics does not provide disaggregated statistics for heat. At the next level, data on the breakdown of industrial heat demand by different temperature ranges are not exhaustive. Often even company staff cannot supply the desired data. In the absence of a detailed analysis of the working temperature range required by the different industrial subsectors, it is difficult to make a practical case for the use of solar thermal for industrial heat or to match solar thermal technologies to the temperature requirements. Even data on the use of solar thermal for heat suffer from a number of deficiencies, such as data quality and availability.

While the collection of data on the contribution of heat to final energy use needs to be included and reported in the national energy statistics, the collection of data on existing applications of solar thermal in terms of knowledge sharing and access can be undertaken by initiatives such as SOLTRAIN. Another possible solution for data collection is to mandate an assessment of solar process heating technologies in energy audits (European Solar Thermal Industry Federation, in IEA and IRENA, 2015).

8.2 Technology barriers

There is growing global evidence of the application of solar process heating in many industrial subsectors. The temperature levels achieved are gradually increasing, as is the scale of the applications. Nevertheless, most solar thermal systems for industrial process heat are small-scale pilot plants. IEA and IRENA (2015) observe that only a third of the 140 projects has collector areas > 500 m^2, and the four largest projects account for 49% of the installed thermal capacity. This is due to technological barriers that have to be overcome.

First, solar thermal systems are not universally applicable, as some sites will be more suitable than others from a solar thermal potential perspective. Second, solar thermal will also only be applicable to companies that have space to implement solar thermal systems, either with applicable roof space[8] or ground space (but note that shading from nearby buildings and objects such as trees can limit the ability of solar thermal systems to produce sufficient energy). However, the abundance of solar resources in the country means that solar collectors will generate a lot of energy before considering losses.

Third, most solar thermal systems are retrofitted. Many of the structures available are not designed for the loads and orientations required for a solar thermal system. Roof material used, such as asbestos, is still prevalent in older buildings. These physical limitations can restrict the installation of solar thermal systems.

Fourth, solar thermal only provides heat energy and is generally optimised for a specific temperature. This limits its adaptability as processes change in industry over time. Furthermore, solar thermal systems have to be specifically designed and installed per site as an integrated system. One of the reasons for this is to ensure that there is relatively equal flow within the system, as hotspots on collectors could cause steam build-up and damage to the system. Fifth, a lot of procedural knowledge is required to plan a solar process heat plant. Such knowledge is not easily forthcoming within the implementing industry.

Stronger research, development and deployment into new solar thermal technologies for process heat can improve the suitability and viability of the installations. Moreover, focusing on small and medium enterprises (SMEs) can help overcome the technological barriers faster. The heat demands per plant for SMEs are relatively small compared to the energy-intensive industry, which makes the integration of solar heating systems easier. An increased number of SMEs would also allow for faster learning-by-doing and declining costs. Finally, given the relative complexity of solar thermal systems, they are best considered in conjunction with energy efficiency, to limit the risk of changes to the process system restricting the long-term effectiveness and usefulness of solar thermal.

[8] Roof space needs to be north-facing to get maximum return in South Africa (south-facing in the northern hemisphere) and able to bear the load of the solar thermal system.

8.3 Non-economic barriers

Awareness of existing solar thermal installations and experiences with them will be critical to creating awareness around the use of solar thermal technologies for industrial process heat. However, as mentioned earlier, not many solar thermal installations for industrial process heat are currently installed. Policy makers and industries are neither aware of these technologies nor do they have large-scale first-hand experience with solar industrial process heat systems. To overcome this barrier, specific awareness-raising campaigns targeting policy makers and industries most suitable for solar thermal process heat, such as agri-processing, could be an adequate solution. In addition, clear and transparent communication about the costs, benefits and practical implications of these technologies will promote (more rapid) uptake.

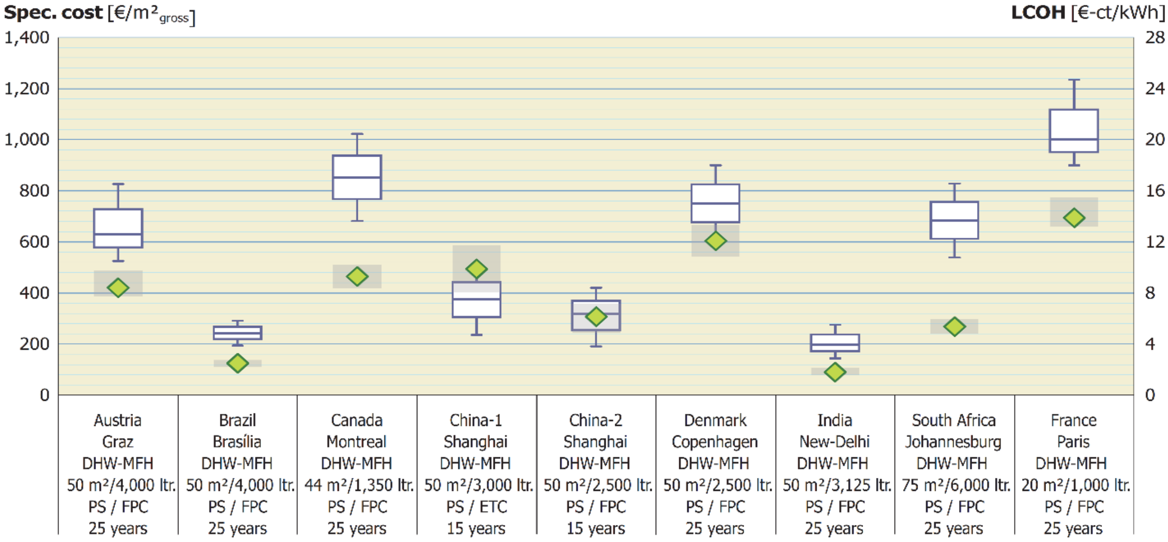
Philibert (2006) also highlights the importance of training engineers and installers to address the lack of solar competence in the sector. Training should not be limited to technical aspects, but should also include sales and marketing people who can advise prospective clients on economic criteria other than merely the 'pay-back' period of the installation. This aspect was also stressed by South African professionals in a workshop convened by WWF-SA (2016).

Developing more experimental projects in the industrial sector, with cooperation between research institutes as well as initiatives such as SOLTRAIN, will not only create greater awareness of the potential applications of solar thermal in different industries but also disseminate the know-how. Scaling up the training programmes on a national level, of the kind currently provided by SOLTRAIN, will not only allow professionals in the field to propose applications to industries, but also raise awareness and overcome the current lack of expertise amongst professionals.

8.4 Economic barriers

The economic barriers to the use and scaling up of solar thermal systems for industrial process heat are many. One of the key constraints to greater uptake of solar heating in South Africa is the relatively high cost of these systems. This is most pertinent when considering how solar heating systems compare to systems elsewhere in the world, as shown in Figure 15. Solar thermal systems generally require a backup energy supply to ensure heating supplies are met when there is insufficient solar irradiance to produce the required heat. This is notable, with current systems in South Africa expected on average to provide 60% of heat (i.e. the solar fraction of heat demand is expected to be 60%) (SOLTRAIN, 2016). However, for that fraction, the fuel cost over the system's lifetime is zero. However, it is clear that South African systems are not cost competitive.

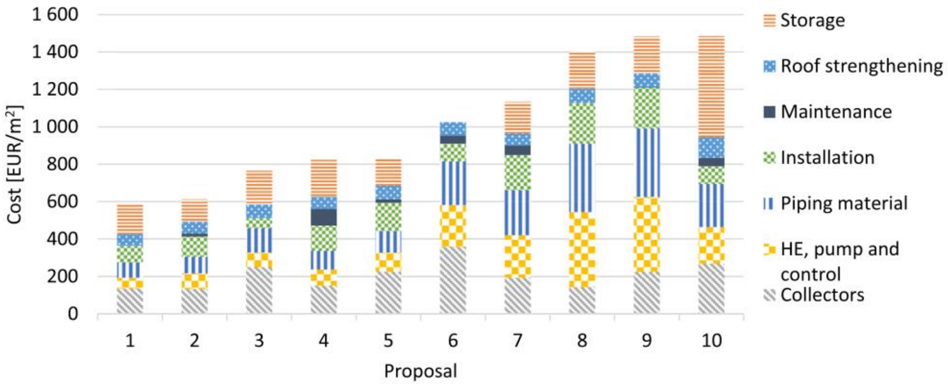
Figure 15: Specific investment costs and levelised costs of solar thermal generated heat for large pumped domestic hot water systems



Source: Mauthner et al. (2016)
Note: LCOH = levelised costs of heat

In this regard it is useful to refer to the bids submitted by service companies to the CBC's request for proposals. Even though it is the largest system considered in the comparison in Figure 16, it is far from the cheapest. The comparison is thus biased as larger systems should have a lower cost per m² as they achieve economies of scale. The significant range in the scope of bids provided by service companies in response to CBC's request for proposals (Figure 16) also highlights the lack of cost competitiveness of the solar thermal industry in the country. This could be indicative of a lack of clear understanding of solar thermal systems in the country, as well as the potential for cost reductions as the technology becomes more established. The range of proposals also highlights the difficulty for companies to evaluate tenders. The value added by the involvement of CRSES has already been highlighted in the report, but the need to contract external expert advice is another cost factor that companies need to consider.

Figure 16: Proposal comparisons and component breakdown from the CBC tender



	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

Source: Joubert et al. (2016, p. 815)
Note: The table below the graph shows the calculated levelised costs of heat (LCOH), IRR and payback period. The figure uses the September 2015 exchange rate of ZAR/EUR = 15.3.

The higher upfront costs of the system hamper the economic viability of solar heat for industrial process systems even though they save on conventional fuel costs. Consequently, companies are often deterred from such an investment in spite of its long-term benefits. The capital-intensive nature of the technology also poses financing challenges. Conventional finance mechanisms only look at the return on their investment and do not take into account positive externalities such as the socioeconomic and environmental benefits attached to the technology.

Another barrier is that to be able to maximise the share of heat provided by solar heating, it needs to be accompanied by storage to allow process heating during non-sun hours, storage for non-production hours, or more advanced control systems to optimise the usage of solar heating. For SMEs, rooftop space and finance opportunities for the upfront costs of storage can be a huge barrier.

Then there is the requirement for systems testing, as required by the South African Bureau of Standards, rather than component testing. Systems testing requires solar thermal systems to be tested and certified as a complete system, i.e. it necessitates re-certification of the entire system if a single component has been changed. For industrial systems, which are designed to purpose, this means that designers have to rely on internationally accredited components, as no local component accreditation exists. This increase in costs (related to certification) in turn results in increased costs of the system as a whole, and limits the development of a local manufacturing market.

Although the increasing temperature ranges covered by solar process heating and the increasing costs and volatility of fossil fuel prices are improving the economics, there is a need for financial interventions to boost the deployment of this technology for provision of process heat given the environmental and economic benefits it offers. The financial gap can be bridged by the government through the provision of economic incentives to companies willing to implement solar thermal for process heat. These incentives need to be aimed at reducing payback periods and can be provided by different schemes, such as low interest-rate loans, tax reduction, and direct financial support.

Concerns about capital costs could also be overcome through the use of innovative contracting as in the Energy Service Company model. This both reduces the risk of inefficient installations and removes or limits the capital cost burden of this capital-intensive intervention. The capital cost is taken up by the installer in return for a share in the energy savings, with guaranteed savings limiting risk, or selling the energy to the company utilising it (at a lower cost than the original supply).

Furthermore, solar thermal can be made even more cost effective when tailored to the specific process heating needs of the plant. At the factory level, large-scale applications can benefit from economies of scale and lowered investment costs, increasing their economic viability. At the national level, the International Energy Agency estimates that costs can be reduced by as much as 20% when a country’s total installed capacity doubles.

As far as the cost of testing goes, it would be prudent to shift to component testing that allows the certification of components, as is done in Brazil, Canada, China, the European Union, India, Mexico and the USA (Hertzog, 2012). With component testing, greater competition will occur as subcomponents of systems are able to compete, not just entire systems. European standards could easily be adopted for the country. This will enable greater local manufacturing as companies are able to specialise and achieve economies of scale on certifiable subcomponents. The ability to adjust designs and replace components would allow greater flexibility in design, as individual components could be adjusted without needing to re-certify the entire system.

9. Conclusion

The application of solar thermal energy for industrial applications has huge unexplored potential within the country. This potential is based on the finding that the industrial sector consumes nearly 30% of the total final energy demand in the country and, within industry, 66% of energy use is on account of process heating. Going by international benchmarks, 38% of that energy consumption is for thermal use in the low and medium temperature ranges. Several solar technologies are mature and their costs relative to conventional energy sources or technologies are continuously declining. South Africa's abundant solar resource, rising energy prices and carbon emission reduction ambitions in the face of a fossil-dominated energy mix further strengthen the case for solar-based process heat. Socioeconomic benefits include affordable energy for industry and a boost to the domestic manufacturing sector.

The agri-processing sector, specifically, has a market potential for 425 to 3 758 GWh of heat per annum with estimated carbon emissions reduction of 110 922 – 942 556 CO_2e tonnes per annum. Going beyond this sector to cover other industrial sectors necessitates investigating the heat demand and temperature ranges required by industrial sectors, as well as the energy sources currently used to fulfil this demand. Detailed research and demonstration will help clarify and resolve technical challenges to integrating solar process heat into industrial processes, and programmatic support from the government will be necessary to remove the barriers to growth in the industrial solar process heat market. In particular, there is a need for financial interventions to address the high costs of systems and to boost the deployment of solar thermal for provision of process heat given the environmental and economic benefits it offers.

References

AEE (Arbeitsgemeinschaft Erneuerbarr Energie) Intec (2009a) Thermal Use of Solar Energy, Southern African Solar Thermal Training and Demonstration Initiative. Stellenbosch, AEE Institute for Sustainable Technologies.

AEE Intec (2009b) Thermal Use of Solar Energy: SOLTRAIN Training Course for Experts and Professionals. Stellenbosch, AEE Institute for Sustainable Technologies.

DEA (Department of Environmental Affairs, Republic of South Africa) (2016) *2nd South Africa Environmental Outlook: A report on the State of the Environment*. Pretoria.

DoE (Department of Energy, Republic of South Africa) (2014) Demand Projections – Residential and Industry. Presentation made at Integrated Energy Planning Workshop, 30 September 2014, Pretoria.

DoE (Department of Energy, Republic of South Africa) (2015) *Integrated Energy Plan. Final Report*. Pretoria.

dti (Department of Trade and Industry, Republic of South Africa) (2007) Implementation of Government's National Industrial Policy Framework: Industrial Policy Action Plan. [Online] Available at: www.dti.gov.za/industrial_development/docs/IPAP%20-3august.pdf [accessed 1 June 2017].

E3 Energy (2016) E3 Energy – CBC Solar Thermal Project. [Online] Available at: https://www.

youtube.com/watch?v=JXANpox482k&t=6s [accessed 1 June 2017].

ERC (Energy Research Centre) (2014) SATIM Methodology v3.2. [Online] Available at: http://www.erc.uct.ac.za/Research/esystems-group-satim.htm [accessed 19 August 2016].

Green Cape, 2017.Energy Services 2017 Market Intelligence Report. [Online] Available at: http://www.greencape.co.za/assets/Uploads/GreenCape-Energy-Services-MIR-2017-electronic-FINAL-v1.pdf [accessed on 1 June 2017].

GreenFoods, 2014. Solar Integration Scheme. [Online] Available at: http://wiki.zero.emissions.at/index.php?title=Solar [accessed 1 March 2016]

Manisha Gulati, Louise Scholtz & Saliem Fakir; 2016; Climate change and the low carbon transition; *in Greening the South African Economy; Scoping the issues, challenges and opportunities*; eds. Swilling, M., Wakeford, J. and Musango, J.K; UCT Press Cape Town

Hassine, I.B. et al. (2015) In: B. Muster, ed. *Solar Process Heat for Production and Advanced Applications: Integration Guideline*. [Online] Available at: http://task49.iea-shc.org/Data/Sites/7/150218_iea-task-49_d_b2_integration_guideline-final.pdf [accessed 1 June 2017].

Hertzog, H. (2012) Component Testing for Solar Water Heating. [Online] Available at: http://greencape.co.za/assets/Uploads/energy-efficiency/Component-testing-for-SWH-120912-1.pdf [accessed 1 June 2017].

Holm, D. (2015) Lessons Learned From SOLTRAIN, South Africa's One Million Solar Water Heaters Initiative and From International Champions – How to Improve Market Penetration in South Africa. In: J. Gibberd & D. Conradie, eds. *Smart and Sustainable Built Environments (SASBE) 2015 Conference Proceedings*, 9–11 December 2015. Pretoria: University of Pretoria.

Horta, P. (2015) Process Heat Collectors: State of the Art and Available Medium Temperature Collectors, SolarPaces Annex IV: IEA SHC Task 49.

IEA (International Energy Agency) (2016) IEA SHC Publishes 2016 Edition of Its Seminal Report – *Solar Heat Worldwide*. [Online] Available at: https://www.iea-shc.org/data/sites/1/publications/2016-06-20-Solar-Heat-Worldwide-2016-Edition.pdf [accessed 1 June 2017].

Intelligent Energy Europe. 2011. Solar Process Heat. Available at: http://www.solar-process-heat.eu/fileadmin/redakteure/So-Pro/IEE-08-425-SO-PRO_Project_fact_sheet.pdf [accessed on 4 Jun 2017]

IEA and IRENA (2015). Solar Heat for Industrial Processes Technology Brief. IEA-ETSAP and IRENA© Technology Brief E21 – January. Available at http://www.irena.org/DocumentDownloads/Publications/IRENA_ETSAP_Tech_Brief_E21_Solar_Heat_Industrial_2015.pdf [accessed 4 June 2017].

Joubert, E., Hess, S. & Niekerk, J.V. (2016) Large-Scale Solar Water Heating in South Africa: Status, Barriers and Recommendations. *Renewable Energy*, Issue 97, pp. 809–822.

Lampreia, J. (2014) Industrial Renewable Heat. [Online] Available at: https://www.carbontrust.com/news/2014/05/industrial-renewable-heat/ [accessed 1 June 2017].

Mannak, M. (2015) The Economic Impacts of South Africa's Energy Crisis. [Online] Available at: www.public financeinternational.org/featre/2015/06/economic-impact-south-africa's-energy-crisis [accessed 1 June 2017]

Mauthner, F., Weiss, W. & Spörk-Dür, M., 2015. Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2013. [Online] Available at: www.iea-shc.org/data/ sites/1/.../Solar-Heat-Worldwide-2015.pdf [Accessed 7 June 2016].

Mauthner, F., Weiss, W. & Spörk-Dür, M., 2016. Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2014. [Online] Available at: http://www.ren21.net/wpcontent/ uploads/2016/06/GSR_2016_Full_Report_REN21.pdf [Accessed 4 July 2016].

Philibert, C. (2006) Barriers to Technology Diffusion: The Case of Solar Thermal Technologies. [Online] Available at: https://www.iea.org/publications/freepublications/publication/Solar_Thermal.pdf [accessed 1 June 2017].

Sager. M., Davies, E., Ritchken, E. 7 Osborne. 2015. Concentrated Solar Power A strategic industrial development opportunity for South Africa.

Available at: http://awsassets.wwf.org.za/downloads/concentrated_solar_power_report_final.pdf [accessed 3 March 2017]

Satgar, V. 2014. South Africa's emergent 'Green Developmental State'? in *The end of the developmental State,* Michelle Williams (Ed), University of KwaZulu-Natal Press, p126-153

Sharan, V., Makarov, I., Scholtz, L., Gulati, M. and Santos, I.T. 2016. Enterprise Efficiency: Experiences of Brazil, Russia, India and South Africa. Paper for Economic Policy Forum. https://economic-policy-forum.org/wp-content/uploads/2016/03/Enterprise-Efficiency.pdf

Solar GIS (2016) Free Download of Solar Resource Maps. [Online]
Available at: http://solargis.com/products/maps-and-gis-data/free/overview/ [accessed 1 June 2017].

SOLTRAIN, 2015. The South African Solar Thermal Technology Road Map (SA-STTRM): Direction for South Africa's solar thermal energy future A discussion document. [Online]Available at: http://www.soltrain.co.za/wp-content/uploads/2016/02/Solar-Thermal-Roadmap_South-Africa.pdf [Accessed 23 February 2016].

SOLTRAIN (Southern African Solar Thermal Training and Demonstration Initiative) (2016) SOLTRAIN Phase III: Current. [Online] Available at: http://www.soltrain.co.za/about-soltrain/soltrain-phase-iii-current-phase [accessed 1 June 2017].

UNIDO (United Nations Industrial Development Organization) (2011) Renewable Energy in Industrial Applications: An Assessment of the 2050 Potential. Vienna.

US EPA (United States Environmental Protection Agency) (2017) Renewable Industrial Process Heat. [Online] Available at: https://www.epa.gov/rhc/renewable-industrial-process-heat [accessed 1 June 2017].

Van Vuuren, P.J., Basson, L., Buckly, A., Kritzinger, K., Terblanche, U., Gulati, M. & Scholtz, L. (2016) Industrial Scale Solar Heat in South Africa: Opportunities in Agri-Processing and Textiles. WWF-SA (unpublished).

Winkler, H. & Marquand, A. (2009) Changing Development Paths: From an Energy-Intensive to Low-Carbon Economy in South Africa. *Climate and Development* 1 (2009): 47–65.

WWF-SA (2016) Renewable Energy for Industrial Process Heat in the Agri-Processing Workshop convened on 17 November 2016, Stellenbosch.

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