POTENTIAL OF SOLAR HEAT FOR INDUSTRIAL PROCESSES: A SUMMARY OF THE KEY FINDINGS FROM SOLAR PAYBACK

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Abstract

Solar thermal technologies present an opportunity to provide clean and renewable thermal energy for process heating when the process temperature is below 400 ºC (maximum solar collector temperature). Project Solar Payback has been initiated to increase the awareness around the technical and economic potential of solar heat for industrial processes (SHIP) within South Africa, India, Mexico and Brazil. This paper outlines some of the initial findings from the first research phase of the Solar Payback project for South Africa. The analysis presented in this paper highlights the food and beverage sector as having the highest SHIP potential in South Africa. This sector is one of largest industrial sectors of the economy and has a number of processes suitable for SHIP integration. However, the extensive use of low cost coal as a boiler fuel in South African industries remains a challenge to the adoption of SHIP. Companies utilising petroleum-based boiler fuels or electrical heating have a higher potential for savings when deploying SHIP.

Keywords: energy, solar, heat, steam, industry, SHIP.

1. Introduction

As shown in Figure 1, the 2015 Energy Balances for the South African industrial sector reveal that electricity accounted for 37% of final energy consumption (energy supplied to final customer), while the direct use of fossil fuels accounted for a combined 55% of consumption [1]. Although electricity currently has the highest emissions factor (CO_2 released per kWh_{th}) of the energy sources presented in Figure 1, the combustion of fossil fuels in industry remains a significant contributor to greenhouse gas emissions. Therefore, the decarbonisation of the industrial sector requires not only electricity generated from renewable sources but also a reduction in the direct use of fossil fuels for applications such as process heating, which currently accounts for 66% of energy end-use in industry [2]. This can be achieved through the development and deployment of technologies that can be utilised to provide clean and renewable heat to the industrial sector.

Solar thermal systems convert incoming solar radiation into thermal energy, which can be utilised for process heating. Key industrial areas in South Africa's major cities typically have a solar resource in the order of 2000 kWh/m2/year (GHI). Despite this significant solar resource there are limited applications of solar heat for industrial processes (SHIP). The database developed by Joubert et al. [3], shows that there are 89 solar thermal plants exceeding a collector area of 10 m2, yielding an installed capacity of 9.7 MWth. However, only 7% of this installed capacity is used to supply industrial process heat and 4% to provide process cooling. Therefore, despite the large potential for SHIP in South Africa further projects are required to raise the profile of this technology.

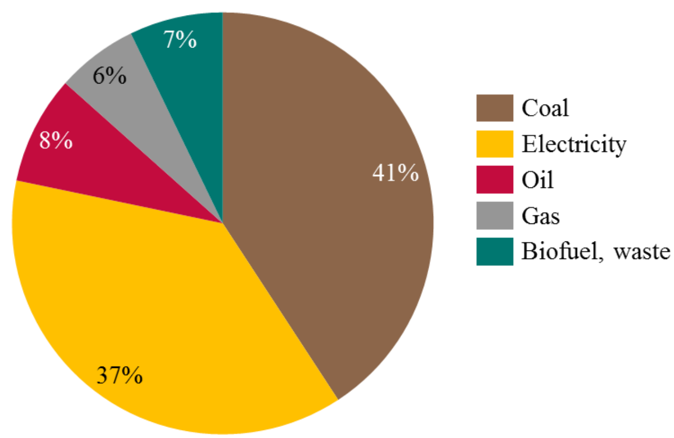

Fig. 1: Final Energy Consumption for the Industrial Sector in South Africa in 2015, according to the International Energy Agency [2]

Project Solar Payback has been initiated to increase the awareness of the technical and economic potential of SHIP technologies within South Africa, India, Mexico and Brazil, in order to foster a willingness of companies to invest in this technology. Measures implemented as part of the project will focus on investors, project developers and policy makers in the four target countries. One of the key aims of the project is to initiate investment in a demonstration plant at an industrial company within South Africa. This paper presents a summary of the initial findings from a SHIP potential study that was completed as part of Solar Payback [4].

2. Suitable industries for SHIP deployment

Solar thermal technologies can be used to generate thermal energy for process heating when the operating temperature is below 400 ºC. The fraction of heat required across different temperature ranges of typical industries is presented in Figure 2, based on research conducted on Germany industries [5]. Sectors such as food and beverage, textiles, chemicals, mining, paper and pulp, and vehicle construction require a significant fraction of heat within suitable temperature ranges.

Solar thermal plants are based on either non-concentrating solar collectors (unglazed, flat plate, evacuated-tube) or concentrating solar collectors (parabolic trough, linear Fresnel, dish). The choice of collector is based on the process temperature range required. A summary of various industrial process within target industries is presented in Figure 3, along with relevant solar collector technologies for each temperature range. Non-concentrating collectors are used for applications below 100 ºC (evacuated tube up to 150 ºC), while concentrating collectors are required to achieve higher temperatures.

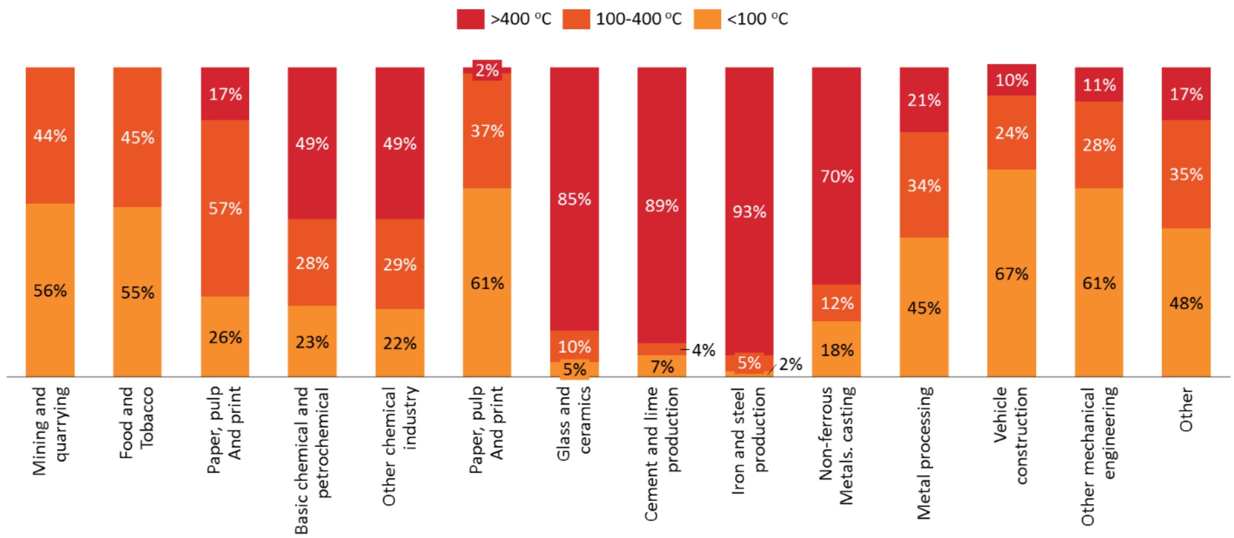

Fig. 2: Breakdown of heat demand within different industries (AGFW cited in [5])

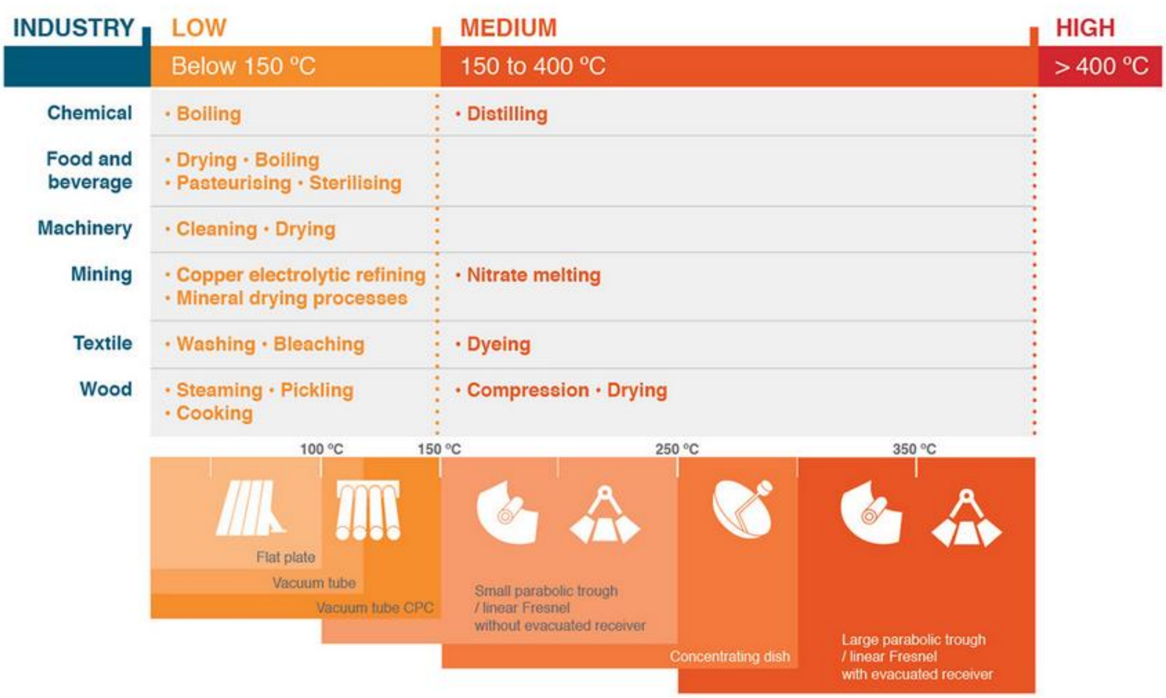

Fig.3: Collector temperature ranges, applications and technologies [6]

3. Analysis of South African Industries suitable for SHIP

3.1 Analysis of Energy Costs

The cost effectiveness of a solar thermal system is dependent on the fuel offset from a competing heating system, typically in the form of steam boilers. Current heating costs for different fuels and electricity is summarised in Table 1, assuming 40-80% conversion and distribution efficiencies from the input energy source. This data supplements the calculations presented by [3]. The calculated heat costs are based on the calorific value of the energy source as well as the energy source cost.

Table 1: Energy costs for process heating in ZAR/kWh

Energy Source	Conversion and distribution efficiency*		
	80%	**60%**	**40%**
Coal Gauteng (R900/ton)	0.15	0.20	0.30
Coal Western Cape (R1500/ton)	0.25	0.33	0.50
SASOL Gas (400-4000 TJ p.a.)	0.40	0.53	0.80
SASOL Gas (4-40 TJ p.a.)	0.56	0.75	1.13
SASOL Gas (0-0.4 TJ p.a.)	0.68	0.90	1.35
Heavy Fuel Oil	0.56	0.75	1.13
Paraffin	0.86	1.15	1.73
Electricity Eskom Night Save**	0.81	1.08	1.63
Electricity City Power**	1.43	1.90	2.85
Diesel	1.36	1.82	2.73
Liquefied Petroleum Gas (LPG)	1.84	2.45	3.68

* Details of calculated energy values provided in [4]
**Average summer and winter energy charge only

The analysis showed that an industrial customer is currently likely to pay between 0.15-0.50 ZAR/kWh for thermal energy generated from coal fired boilers (excluding boiler CAPEX, and operation and maintenance cost). The relatively low cost of coal indicates why it is extensively used in process heating applications in South Africa. However, cost of coal is higher in the Western Cape than in Gauteng due to higher transport costs.

Natural gas has an emissions factor that is 40% lower than coal and it is therefore a cleaner energy source for process heating. However, natural gas is only available to companies with access to the gas grid, which has a limited geographic footprint in South Africa. Costs for SASOL gas range between 0.40-1.35 ZAR/kWh, depending on annual consumption range from SASOL and heat generation and distribution efficiency.

Petroleum based fuels such as HFO, paraffin, diesel and LPG, as well as electricity, have heating costs ranging between 0.56-3.68 ZAR/kWh and therefore present the best opportunity for shorter Payback periods for a solar thermal plant.

One advantage of a SHIP plant is the fixing of energy costs for the operational period of the plant, which is the order of 20 years. Companies utilising petroleum fuels for process heating are subject to volatile price changes due to the international oil price, and ZAR/USD exchange rate. Due to the large-scale capacity expansion programme undertaken by Eskom, electricity in particular has seen significant increases above inflation in recent years.

A proposed carbon tax of 120 ZAR/tCO_{2e} will also increase the cost of using fossil fuels and electricity for process heating. Due to the reliance on coal fired power generation in South Africa, electricity has the highest emissions factor of all the energy sources analysed. However, as the penetration of renewable energy generators such as solar PV and wind increases, the emissions factor associated with electricity will decrease. Table 2 shows the cost of electricity will increase by 0.11 ZAR/kWh of input energy (excluding efficiency), while that of fossil fuels will increase by 0.02-0.04 ZAR/kWh.

Table 2: Increase on Input Energy Costs due to Carbon Tax (120 ZAR/tCO_{2e})

Energy Source	Emissions* (kg CO_2/kWh)	Cost increase*** (ZAR/kWh)
Coal	0.34	0.04
Natural Gas	0.20	0.02
Paraffin	0.26	0.03
Diesel	0.27	0.03
LPG	0.23	0.03
Electricity**	0.88	0.11

*Based on emissions factors from [7],
**Based on CSIR Energy Centre PLEXOS model of Power System (2016/2017)
***Based on input energy only excluding conversion and distribution efficiency

3.2 Steam Demand for Process Heating

There is currently a lack of detailed statistics on the end-use of energy for process heating within South African industry. One of the key objectives of the Solar Payback potential study was to contribute new data on the use of process heating below 400 ºC. Over this temperature range for industrial processes, pressurised steam is commonly used as the heat transfer medium. A centralised boiler is typically utilised to supply steam to a range of different processes throughout a plant.

Due to the limited scope of the project, a focus was placed on the use of package boilers (<16 MW in capacity). Therefore, the larger boilers in the sugar, chemicals and paper industries were excluded from this analysis, as well as boilers for power generation. As part of the research, experts within the steam boiler field were consulted to estimate the demand for steam within the identified industries of food and beverage, textiles, paper and pulp, chemicals and mining.

Indicative figures for the installed capacity of boilers within the identified sectors were used to estimate the steam demand, based on an assumed capacity factor of 22% (8h shift, 5 days per week, and 245 days per year). Although large boilers ideally operate continuously it is not uncommon for smaller boilers to operate at a lower capacity factor. Should a boiler operate at a higher capacity factor then the demand for heat in the form of steam would be higher than estimated in this work and the breakdown in energy use between industries would shift. Figure 4 shows that an estimated 26.5 PJ of heat energy is transferred as steam annually in the assessed industries. Assuming a 75% conversion efficiency, this yields an input energy value of 35.3 PJ.

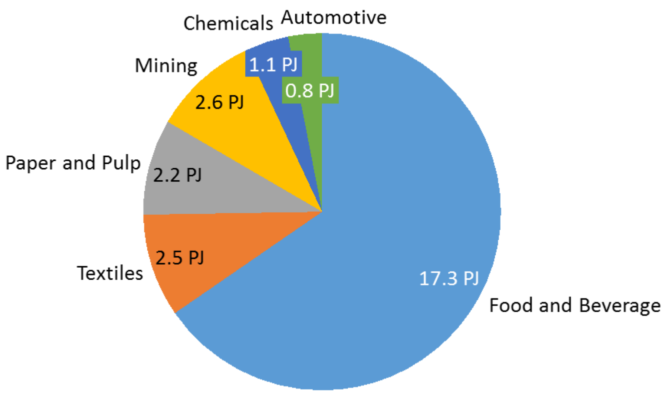

Fig. 4: Breakdown of estimated annual steam demand (Total: 26.5 PJ, excluding conversion efficiency)

The results of the analysis show that the demand for steam is highest in the food and beverage sector. However, it is difficult to track the migration of boilers between industries. Therefore Figure 4 should not be considered absolute, but rather indicative of opportunities for SHIP. This analysis is also only focussed on the identified industrial sectors and excludes boilers installed in commercial and public buildings as well as laundries, where steam is also extensively used.

Process heating outside the scope of steam boilers was not included in the analysis. A significant research effort is required to document the energy utilised for all forms of process heating within industry. Experts within the chemical industry indicated that electric process heating is extensively used, while gas heating through LPG is also used in painting processes in vehicle manufacturing.

3.3 Energy Sources for Industry Sectors

As described in Section 3.1, the return on investment of SHIP plants is dependent on the energy source that is offset from the current heating system. As part of the Solar Payback research, an analysis was conducted to determine the breakdown of fuels consumed by relevant SHIP sectors. Three data sources were available for this study, which are described below. Table 3 provides a comparison of the number of companies in each dataset, as well as the total energy consumed.

<u>*National Cleaner Production Centre (NCPC) Energy Audits*</u>: As part of the energy audits conducted by the NCPC, data is collected on the consumption of fuel and electricity from each company. This data was aggregated by industry type and provided as part of this research project. Figure 5 provides a comparison of ratio between fuel and electricity.

<u>*City of Cape Town Air Quality Management*</u>: The Air Quality Management department from the City of Cape Town maintains a database of industrial combustion equipment and energy consumption. Aggregated data was provided on the fuel type and annual consumption for companies in the database.

<u>*Ozone Business Consulting (O_3BC) Energy Audits:*</u> O_3BC is a consulting company that conducts industrial market surveys in South Africa. Through projects for Eskom IDM, O_3BC have collected a database of energy usage within South African industries up to the year 2009. Therefore, it should be cautioned that this data could be out of date, (especially for the textiles sector). In general, this data covers the largest and most energy intensive companies in each sector.

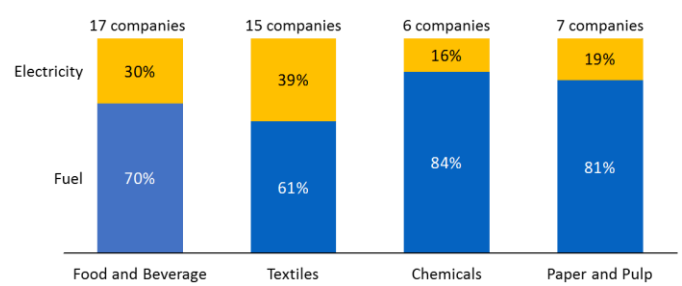

Fig. 5: Comparison of fuel and electricity consumption in NCPC audit data

The results of the analysis are presented in Figure 6. In the food and beverage sector all datasets identified the significant use of coal as a boiler fuel. The data shows that there is a correlation between total energy consumption and the type of boiler fuel.

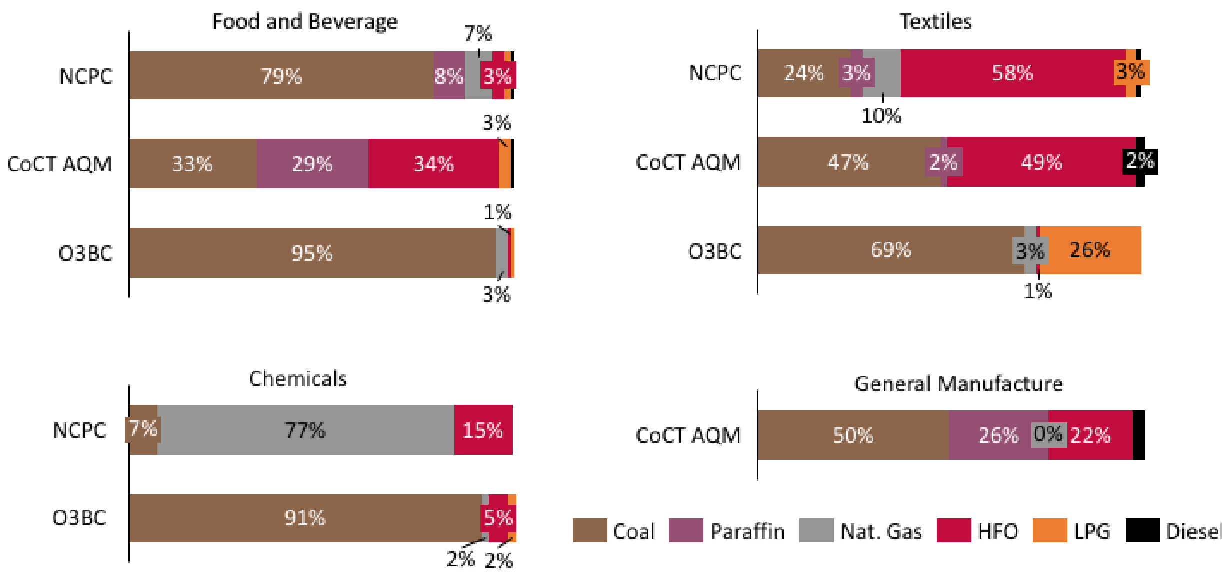

Fig. 6: Breakdown of fuel consumption in target SHIP industries (company numbers and energy as per Table 3)

Table 3: Description of datasets for fuel consumption analysis

Sector	NCPC		CoCT AQM		O_3BC	
	No. Comp.	Energy [PJ/a]	No. Comp.	Energy [PJ/a]	No. Comp.	Energy [PJ/a]
Food and Beverage	44	1.43	118	1.52	39	16.7
Textiles	15	0.14	41	0.48	9	0.29
Chemicals	27	3.4	Not Available		35	3.1
General Manufacture	Not Available		77	0.9	Not Available	

Energy intensive companies such as those in the O_3BC dataset are most likely to use large central coal fired boilers, while smaller companies such as those in the CoCT dataset also use HFO or paraffin as an alternative to coal. The location of companies in the CoCT dataset in the Western Cape is also a possible reason for the reduction in the use of coal.

All three datasets show a lower fraction of coal usage in the textiles sector and an increase in the use of HFO. On average the textiles companies surveyed are less energy intensive than the larger food and beverage companies. There is poor agreement within the chemicals sector between the NCPC and O_3BC datasets, which is likely caused by the diverse range of companies and processes in this sector and limited sample size.

3.4 Number of Companies and Turnover

Economic growth in a sector, combined with a large number of companies is considered to be a positive aspect for SHIP deployment. As shown in Table 4, the chemicals, and the food and beverage industries are two of the largest sectors of South Africa industry. The food and beverage sector is one of the only industry sectors to experience high growth over the past decade.

The number of registered companies in each sector was attained from the business register from Statistics South Africa. Data was only provided down to SIC level 2. Through engagement with industry it was highlighted that the number of registered companies in each sector was not representative of sizeable manufacturing operations. Therefore, alternative datasets were also sourced. Once a company wage bill exceeds ZAR500k it is required to register with a Sector Education and Training Authority (SETA). The number of levy paying members are generally published by SETAs and give a more representative view of the number of sizeable manufacturing companies in each sector. The number of companies that have been documented by O_3BC was also provided for comparison.

Table 4: Number of companies and turnover

Industry Sector	SIC Code	Output* (million R)	Number of Companies		
			StatsSA	SETA**	O_3BC
Food, beverages and tobacco	30	438 319	8977	1892	1149
Clothing, textiles, leather goods	31	78 297	6495	874	1730
Wood and paper; publishing and printing	32	193 201	3999	2376	Not Available
Petroleum products, chemicals, rubber and plastic	33	478 053	6985	2010	1943
Transport equipment	38	223 892	10146	256 (auto)	Not Available

*Data from Quantec Easy Data [9]
**SETAs include FoodBev, Fibre Processing and Materials (FP&M) and CHIETA [9-13]

If it is assumed that the SETA figures are the most representative of sizable manufacturing operations, then SIC30, SIC32 and SIC33 are highlighted as having a large number of companies (in the order of 2000). The textile sector in South Africa has seen a significant reduction in company numbers over the last decade, with the FP&M SETA having 200 levy paying textile companies. In terms of number of companies and sector size the food and beverage, and chemicals have the highest potential.

4. Conclusions

There is currently a lack of data available on the end use of energy within different industries. This paper has presented a number of new sources of data on energy consumption in various sectors that are suitable for SHIP deployment.

The analysis of steam demand identified the food and beverage industry as having the highest potential for SHIP projects in South Africa, with two thirds of installed boilers operational in this sector. According to [5], 55% of the heat demand in this sector is below 100 ºC, and 45% is between 100-400 ºC. There are a number of international case studies of successful SHIP plants in this sector, which is also experiencing growth in South Africa, with a large number of active companies.

One of the challenges to the adoption of SHIP in large food and beverage companies is the extensive use of large coal fire boilers, with fuel costs in the order of 0.15-0.5 ZAR/kWh. It is critical to highlight that this low coal cost does not take into consideration the externality costs associated with coal mining and combustion. Smaller companies, particularly in Western Cape also utilise HFO or paraffin as a boiler fuel, which when offset with SHIP yields attractive payback conditions.

There remain opportunities for SHIP deployment in the textiles, chemicals, automotive and paper and pulp industries. The steam demand in chemicals and paper and pulp sectors is likely underestimated in the chemicals and paper and pulp sectors due to the focus on smaller package boilers in this work. The use of process heating outside of steam demand is also not captured in the analysis.

5. Acknowledgements

The author’s wish to acknowledge the financial support from the International Climate Initiative the project Solar Payback. The support of the NCPC, City of Cape Town and Ozone Business Consulting is also acknowledged for providing new data on energy usage by companies.

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