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LOCALISATION POTENTIAL OF LINEAR FRESNEL CSP IN SOUTH AFRICA

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Abstract

Concentrating solar power (CSP) plants are distinguished by large upfront capital cost and low operational cost. For a CSP roll out in South Africa it is therefore critical to maximise the local supply chain in order to achieve value gain and highly needed job creation in the country. Specifically linear Fresnel (LFR) has been identified as a technology suitable for the South African environment as an electricity generating system, processes heat provision, or a steam augmentation technology for coal fired power stations.

The focus of this paper is the investigation and quantification of the readiness of the South African industry to establish a localised supply chain with an emphasis on LFR concentrating solar thermal energy (CST) applications. Literature results on related CSP technologies were transferred and applied to the LFR system.

The analysis suggest that throughout the different CSP LFR applications a high percentage of above 70 % can be sourced in the country today and up to almost 80 % in the long term, assuming a shallow CSP penetration of the South African energy sector, as stipulated in the IRP. Further increase in local content is possible and dependent on CSP market size and reliability.

Keywords: Linear Fresnel; Localisation; Industrialisation; CSP; CST;

1. Introduction

South Africa's electricity sector is faced by a series of problems in the near future. Firstly, the country is largely dependent on the fossil resource coal, which is more rapidly diminishing resource than previously thought [1]. Secondly, new coal based generated power is currently leading to escalating generation cost in the country, putting strain on the availability of low cost power supply. And further, coal based power is leading to a significant carbon footprint of about 0.9 kg of CO_2 per kWh generated, opposing efforts on climate change mitigation [2].

In efforts to provide an affordable and renewable electricity mix for South Africa, concentrating solar power (CSP) has been identified as an important part of the future generation capacity [3]. To successfully address the nation's demand, an installed capacity of up to 24 GW CSP by 2030 is seen as required, which will equate to 27 % of total installed capacity [3]. Such a large-scale CSP roll-out is believed to acquire an investmen in excess of $100bn [4].

However, to date, CSP systems are considered to be as sophisticated technology, with a limited number of companies, almost exclusively from Spain, Germany and the United States, sharing the market. This has been evident during the first bidding round of the Renewable Energy Independent Power Producer Procurement

Programme (REIPPPP, known as REBID), where the two awarded CSP projects – Khi Solar One and KaXu Solar One – were awarded to Spanish-based Abengoa Solar.

To stimulate positive effects of awarding large CSP contracts to foreign companies, government and industry have committed to increasing the shares of local content. From 2016 onwards the committed part of locally spent capital is set at 35 % [5]. In the longer term this threshold will be increased to 75 % of local share [5]. To reach 25 % to 35 % localisation does not require local manufacturing [6], as the project development provides sufficient scope to spend capital locally; this can, amongst others, be site preparations, solar resource assessments and concrete foundations. Further increases in the local share, however, requires the manunfacturing of components in the country, which will have the desirable effect of job creation. Out of the three CSP collectors that achieved commercial status – parabolic trough, central receiver and linear Fresnel – the LFR technology has the highest potential for localisation of manufacturing [7] [8] [9] [10]. This is mainly explained by the low system complexity, leading to a reduction in the need of advanced engineering materials and manufacturing processes [11].

This paper attempts to quantify that possible localisation content of linear Fresnel[1] CSP plants for the South African environment. Due to inherent system similarity to other LFR CST applications the results are related to such applications. Specifically, this paper discusses the localisation potential for different CSP applications as well as LFR CST applications in the field of steam augmentation to coal power stations, as well as industry process heat applications.

2. The linear Fresnel application spectrum

Concentrating solar power (CSP) is the most prominent concentrating solar thermal (CST) application, where the CST collector is combined with a power block, usually a steam Rankine cycle, to generate electricity. However, the possible range of CST applications is far larger (Figure 1).

Figure 1: CST applications (picture reference from top left to bottom right: [12], [13], [14] & [15])

It is important to understand the different applications and their requirements, as each field of application of a CSP collector is distinguished by its individual technological demands. The technological difference in

[1] When referred to linear Fresnel CSP collectors in this paper, the authors refer to systems with single pipe cavity receiver and direct steam generation (DSG)

between different Linear Fresnel systems for different applications can be separated by the temperature range and pressure required.

2.1. CSP

The CSP section is split into two segments: grid connected, and off-grid plants.

2.1.1. Grid connected

The technological developments of grid-connected power plants are mainly driven by the strive for lower levelised cost of electricity (LCOE). Project developers are, amongst other important considerations, selecting a collector technology for a CSP plant that promises the highest profit. Hence, LFR technology competes with other CSP systems, such as parabolic trough and central receiver for construction a share of the CSP market.

The highest levers on that are reduction of the plant capital cost and increase of production output. Linear Fresnel was invented in an attempt to achieve major capital cost reduction [7]. To further reduce LCOE, the developers attempt to increase the system output. Carnot's theorem defines the ideal thermodynamic efficiency with $\eta = 1 - \frac{T_C}{T_H}$. Thus higher temperatures achieved in the collector lead to higher efficiency and electricity production. This has been achieved by continuously increasing the steam production temperatures [16]. The first prototype LFR systems produced saturated steam at below 300 °C and pressures at around 50 bar [17] [18]. However, the upgrading of prototype systems has led to steam temperatures of above 500 °C. This is achieved by systems utilising direct steam setups [16].

2.1.2. Off-grid systems

Off-grid CSP systems have relevance in the South African context, as numerous rural communities are to date not connected to the existing national grid. Next to low electricity generation costs, for such systems automation and robustness are paramount. For the scope of this work a solution to provide rural communities, with automated saturated steam linear Fresnel power plants is investigated. Technical implications such as remote controlling are not addressed. The saturated steam system allows for reduced steam temperature and pressure to reduce system complexity and risk. Typical saturated steam conditions are in the range of 270 °C and 50 bar (see LFR plants PE1 and PE2, as well as central receiver plants PS10 and PS20 [17]).

2.2. Non electricity applications

2.2.1. Steam augmentation

Steam augmentation is the provision of steam generated in a CST system to a fossil fuel fired power plant in order to reduce coal consumption or to increase the power station output with unchanged coal supply. The steam properties are dependent on the individual power station technology. Typical steam requirements are listed with 371 °C and 538 °C, each at 165 bar, depending on whether the steam is added before or after the superheating section of the power plant [19].

2.2.2. Process heat applications

The CST applications for process heat are a vast field, incorporating a variety of steam requirements for individual applications. It can be noted that generally low temperatures (below 250 °C) are required [20].

2.3. Poly-generation

Co- and tri-generation are a combination of two or three applications of one collector (also poly-generation). An example for co-generation is a power plant producing electricity and generating hot water with the exhaust heat. The requirements on poly-generation plants are dependent on the individual sub-applications.

2.4. Summary of LFR applications

As shown above, every system has its individual target temperature range and steam pressures. This leads to variable design requirements, depending on the specific application. Hence, LFR technology cannot simply be discussed as one technology in terms of localisation potential; the context and application has to be differentiated. The LFR applications are thus summarised into categories defined by the systems operating target temperature range (Table 1).

Application	Temperature	Pressure	Reference
CSP - Utility scale	450 °C – 500 °C	100 bar	[16]
CSP - Off-grid	270 °C	50 bar	[17]
Thermal power plant steam augmentation (Before superheaters)	371 °C	165 bar	[19]
Thermal power plant steam augmentation (After superheaters)	538 °C	165 bar	[19]
Process steam	Low temperature saturated steam	Low temperature saturated steam	

Table 1:Linear Fresnel applications and steam requirements

3. Linear Fresnel plant costs and power plant layout

The estimation of the localisation potential is based on a linear Fresnel collector cost breakdown by Mertins [8]. In that document the optimisation of a linear Fresnel collector for steam temperatures of 400 °C was investigated [8]. The cost data was manipulated for this paper to incorporate evacuated tubes into the model and add a power block to the economic investigation.[2] Further, mirror-cleaning robots are excluded from the investigation, given the vast employment opportunity for unskilled workers for mirror washing.

3.1 Absorber

For temperatures above 400 °C the application of evacuated tubes instead of standard pipes with selective coating provides economic benefits [16]. To this end a second absorber cost model has been developed, incorporating the evacuated tube system. It was assumed that the cost of an evacuated tube system is 70 % above the standard high pressure pipe with selective coating. The remaining absorber costs are kept the same, assuming that the evacuated tubes are welded in the same section length as the standard pipe. The absorber cost breakdown for the system by Mertins [8] and the higher temperature evacuated tube system is given in Table 2.

Element	Standard absorber system [€/m]	Evacuated tube absorber [€/m]
Absorber pipe system incl. selective coating/ evacuated tube system	217.9	370
Welding	116.4	116.4

[2] All conversion rates are R9.5 per € and R7.3 per US$

CPC & glass pane	44.2	44.2
Fastening & structure	136.7	136.7
Transport	26.4	26.4
Assembly	112.6	112.6
Total cost	654.2	805.1

Table 2: Cost breakdown of absorber system for standard pipe and evacuated tube

3.2 Power block

The cost assumptions of the power block were based on literature findings. This paper distinguishes between two electricity generating linear Fresnel CSP plants: a large scale utility version; and a small scale off-grid solution. The power block cost assumptions are provided in Table 3.

Plant type	Temperature [°C]	Power block cost [t€/MW]	Reference
Superheated utility scale	500	700	[7]
Saturated off-grid	270	420	[21]

Table 3: Power block cost assumption

3.3 Simulation environment

The simulation described in [22] was extended for the purpose of this study to allow the implementation of a second absorber pipe system with different thermal characteristics. The simulation was based on hourly DNI data for Stellenbosch with an average annual value of 2 342.0 kWh/m^2. The power plant dimensions were optimised, based on lowest levelised cost of electricity (LCOE). The LCOE calculation was based on the NREL guidelines [23]. To calculate the local content, a representative utility scale CSP plant dimension was developed, as shown in Table 4. For the off-grid plant the dimensions developed in [22] were used.

CSP plant	Steam conditions [°C/bar]	Turbine capacity [MW]	Power block efficiency [%]	Collector size standard cavity receiver [m^2]	Collector size evacuated tube [m^2]
Utility scale	500/100	50	35.8	225 000	30 000
Off-grid	270/50	2	23.4	17 800	0

Table 4: CSP plant dimensions

4. Linear Fresnel localisation

4.1 Background and assumptions

The localisation possibilities of the CSP industry in South Africa have been investigated by the World Bank in 2011 [24]. That report is limited to the parabolic trough technology and its components and subsystems. However, since LFR technology works on similar principles to parabolic trough, and can be seen as a simplified version of it, the information contains high value, directly applicable to the LFR collector.

Additional assumption, not made in the World Bank report, had to be made regarding the power block and the absorber subsystems. The power block was assumed to allow for 60 % of local expenditure [24]. The localisation of the absorber pipe is depending on the operating conditions. High-pressure pipes can be sourced in the country. However, the sputtering process for both systems, to apply a selective surface, requires sophisticated and expensive machinery [25]. The fact that sputtering machinery has a high annual production volume [26], translated into multiple hundreds of MW in CSP capacity, suggests that the finalised pipes - standard and evacuated – will be imported from overseas [25]. In case of the evacuated tubes, the finished evacuated tube system is purchased on the international market.

Lower temperature applications such as saturated steam CSP plants or process steam plants can be equipped with selective surfaces that are stable at air and can be applied as paints [27]. With such coatings, the high pressure (in the case of saturated steam LFR CSP plant ~50bar) absorber pipes can also be sourced locally.

4.2 Localisation prediction

The prediction of localised content for linear Fresnel CST applications was investigated in the short-, and long-term perspective. These timeframes were chosen to identify the immediate potential for localisation of LFR, as well as the long-term potential. However, it has to be noted that the long-term potential is linked to the current foreseen CSP deployment in South Africa, regulated through the Department of Energy's Integrated Resource Plan (IRP). The possible amount of local content for different LFR CSP and CST applications is shown in Table 5.

LFR application		CSP Utility scale		CSP Off-grid		Steam augmentation		Process steam	
Forecasting period		Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term
Mirror field	[%]	93	95	91	92	92	95	96	96
Absorber system	[%]	65	81	100	100	65	81	100	100
Receiver structure	[%]	100	100	100	100	100	100	100	100
Miscellaneous	[%]	100	100	100	100	100	100	100	100
Additional expenditure	[%]	78	100	78	100	78	100	100	100
Power block	[%]	60	60	60	60	NA	NA	NA	NA
Infrastructure & land preparation	[%]	100	100	100	100	100	100	100	100
Contingencies	[%]	100	100	100	100	100	100	100	100
Total local content	[%]	74	77	77	79	87	96	99	99

Table 5: Local content as percentage of capital cost

The local content for all investigated LFR CST solutions ranges between 74 % and almost 100 %. The highest rate can be achieved by the process steam applications. This is due to the reduced system requirements due to low temperatures and pressure. It has been shown that a LFR process heat system can fully be designed and built in South Africa [28].

The steam augmentation solution can score 87 % to 96 % in the long term, where the restriction to higher localisation abilities is the use of imported evacuated tubes and sputtering required for the non-evacuated LFR field. The same applies to the high temperature CSP solution, where additionally the power block reduces the local manufacturing share. Steam turbines are also in the long term assumed to be imported [24].

The off-grid CSP application however can be supplied by local piping, as the lower temperatures allow for selective coating materials with less sophisticated processes [27]. However, the power block will remain to have high non-local content.

5. Hurdles hindering further localisation of linear Fresnel power plants

For the results indicated above, the underlying assumption was a CSP rollout at the IRP scale. The local content of CSP LFR plants can range from 73 % to 81 %. This is in range of the statement of Areva Solar, claiming that 60 % to 80 % of their technology can be of local content [29].

The remaining gap to full localisation is mainly due to the limited scale of the regulated CSP market. A market development tending towards the ambitious figures developed by Edkins et al. [3] could lead to South Africa being the world's largest CSP market. This can make it feasible for evacuated tube manufacturers and CSP turbine developers, amongst others, to erect manufacturing plants in the country.

Pancho Ndebele, CEO of FG Emvelo (a project developer planning LFR CSP plants in South Africa) points out that the lack of a reliable long-term perspective of the market is a crucial hurdle for setting up local manufacturing plants [30]. This view is confirmed by other partners that require capital-intensive upgrades or new plants to supply a CSP industry.

Some technology components, such as evacuated tube and power block systems, can have similarities with systems of other CSP technologies. Hence a general growth of other CSP technologies can positively reflect on the local share of linear Fresnel. The effect of market size on CSP localisation (here parabolic trough and central receiver technology) is highlighted for the MENA region in [24], where the local share is predicted to increase from 26 % to 57 % by increasing the CSP market size from 0.5 GW to 5.0 GW.

6. Conclusion

The initial findings of this paper suggest that a greater portion of the linear Fresnel technology option can be sourced in South Africa. This is a particularly valuable outcome to the industry for applications where the linear Fresnel collector can be applied without a steam turbine power block. This is important for applications in process heat/cooling and steam boosting for coal-fired power stations. For an electricity producing linear Fresnel plant, however, the power block and its components will, to a large extent, be sourced from abroad.

It can be seen that the government targets, committed to in the Green Energy Accord, seem not to be a hurdle for linear Fresnel CSP systems. In the short term a localisation share of above 73 % is possible, reaching to almost 90 % for a utility scale CSP plant. Exploiting this potential could lead to a significant advantage over other CSP technologies in the bidding in the REIPPPP.

Other CST applications achieve even higher localisation ratios, mainly contributed by the low local content of the Rankine cycle power blocks required for electricity generation. Process heat applications can with today's industry capabilities be fully developed and built in the country.

The path to higher local content is dependent on the future market size and its reliable long-term stability, allowing companies to take bigger investments to build local manufacturing capabilities.

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