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# Overview of predictive CSP spread scenarios and its opportunities

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## ABSTRACT

This article illustrates the prospects as well as the problems that an implementation of Concentrating Solar Power (CSP) with storage technology in the South African infrastructure entails. A short overview of current CSP technologies is given. The paper attempts to examine various factors that have an effect on the cost of CSP plants and offers an overall review of the opportunities CSP has for the country. Furthermore, it attempts to give a forecast on how the costs of CSP will develop and explains why a near-future decision, concerning the South African power system, is necessary.

The paper concludes that South Africa, with its high solar irradiation values holds a naturally very high potential for this technology and suggests integrating CSP as a peak-load server in the short term, due to the financial incentives the morning and evening demand cause. Assuming decreasing technology costs in the long term, it could as well function as a suitable intermediate- or base-load alternative.

## INTRODUCTION

Throughout the last 20 years South Africa (SA) faced a large number of various power supply problems. Especially in late 2007, the country suffered from several rolling power blackouts. Therefore, South Africa's Department of Energy (DoE) published the Integrated Resource Plan (IRP) in March 2011, with its objective of establishing a certain mix of renewable energy supplies. The IRP attempts to achieve steady progress towards a future, efficient and sustainable power supply for SA, within the given economical and geographical context. The updated 2013 IRP tends to expand the renewables section to cover nearly 25% of SA's energy demand by 2030.

This ambitious modification of SA's electrical infrastructure does not necessarily have to be considered a problem, but could as well be determined an opportunity for the country, given its high solar radiation and the potential an innovative alternation holds. Historically, innovativeness is very likely to result in economical advantage and indeed, on a closer look, it becomes obvious that a restructuring of the South African energy system is inevitable. In her paper, Sara Grobbelaar [1] gives a good summary of the current situation: 'CSP is a young technology and there is still space in the global market for South Africa to become involved in technology development and large-scale manufacturing.'

This paper does not only state that a quick and resolute decision is required at this point, but also provides an opinion why a decision in favor of CSP is required. The objective of the paper is to explain why a certain amount of CSP capacity should be installed in SA.

## NOMENCLATURE

| | | |
|---|---|---|
| *LCOE* | [ZAR/kWh] | Levelized costs of electricity |
| $I_t$ | [ZAR] | Investment expenditures of a certain power plant in the year *t* |
| $M_t$ | [ZAR] | Operation and maintenance expenditures of a certain power plant in the year *t* |
| $F_t$ | [ZAR] | Fuel expenditures of a certain power plant in the year *t* |
| $E_t$ | [kWh] | Generated electricity of a certain power plant in the year *t* |
| *r* | | Discount rate |
| *n* | | Typical life time of the system |
| $W_{in,sol}$ | [Nm] | Amount of energy the plant is provided with (solar) |
| $W_{out,el}$ | [Nm] | Amount of energy the plant produces (electric) |

Special characters

| | | |
|---|---|---|
| $\eta$ | [-] | Overall efficiency of a plant |

## CURRENT SITUATION

As one can see in figure 1 the current electricity generation mix is dominated by coal. Furthermore, oil accounts for a large proportion of electricity generated by open cycle gas turbines during peak demand.

In a worst case scenario, in which SA would abide by fossil fuels, the costs for energy are likely to augment quickly, due to the decreasing fossil fuel reserves and their snowballing prices. Scenarios concerning an infrastructural rollout for natural gas imports were made in the updated IRP version [3] [4] [5]. The Mozambique gas fields (Temane and Pande) could deliver, what is believed to be a sustainable energy source. Still, carbon tax costs are most likely to be a more pressing issue in the future and an insistence on conventional energy sources could result in dependency on other countries, for instance as recently seen in Ukraine, which is currently suffering from their dependency on Russian gas supplies.

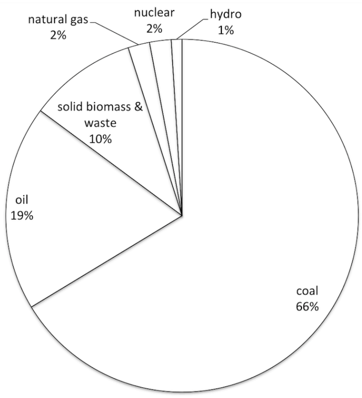


**Figure 1** South African energy mix 2013 [2].

Hence, the consequences will have to be properly considered and, as aforementioned a near-future turnaround is most desirable in order to acquire a solid position on the global renewable energy market.

However, even in the updated IRP, CSP is allocated with only 1.3% [3] [4] [5] of the generating capacity by the end of the planning period and not considered a suitable electricity source for the upcoming generation of power plants. This is most likely caused by the current Levelized Cost of Electricity (LCOE). At the moment the LCOE of CSP is much higher than other intermediate- or base-load energy supply technologies (e.g. 2.0 R/kWh for a CSP plant) [6].

## MEETING PEAK DEMANDS WITH CARBON-NEUTRAL ENERGY SOURCES

Nevertheless, it is often forgotten, that solar technologies and specifically CSP, offer numerous benefits for SA. Figure 2 portrays a typical demand curve for a summer (black) and winter (grey) day. Especially in the winter, the graph displays two power peaks. One in the morning and one in the evening, which provides challenges associated with inadequate supply and is likely to result in higher power prices. In an effort to restore market balance it is necessary to provide a supply curve, which is approximated to the demand. In order to meet these power peaks, so-called peaking power plants are required.

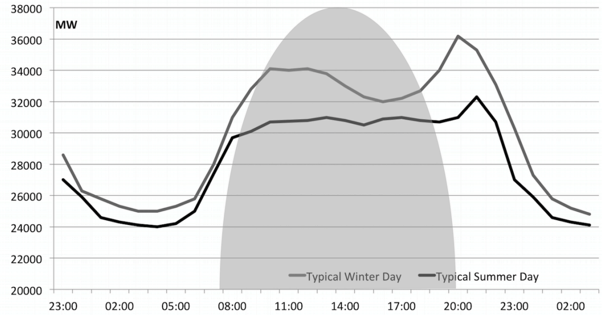


**Figure 2** Demand of a typical South African winter (grey) and summer (black) day [7].

Due to the rudimental supply/demand mismatch, Eskom allocated a 3.94 ZAR/kWh refund for electricity during peak hours (Renewable Energy Feed-In Tariff - REFIT), which equals to 270% of current base-load tariffs.

The shimmed, grey curve in Figure 2's background illustrates the Direct Normal Irradiance (DNI) of a sunny day. It is obvious, that Photovoltaic (PV) will only generate electricity while the sun is shining, which makes it impractical to meet the average electricity demand. Especially during the evening peak, when most power is required, the power network is in need of a flexible and sustainable electricity source.

Currently, the peak demands are met by several open-cycle gas turbines (OCGT) (see figure 1), which makes use of expensive electricity generation technologies with an LCOE up to 5 ZAR/kWh. Last year, Eskom was forced to spend a massive ZAR 10.5-billion on diesel fuel to enable the OCGTs, which contributed 3621 GWh of the 230 938 GWh produced by the coal-heavy utility [8].

However, Eskom made a good attempt on tackling South Africa's general supply problems by integrating certain renewable energies into the country's power supply system. In their "Transmission Update" (4th Sept. 2014) [9] Eskom announced that for the first time more than 1000 MW of renewable energy projects were declared fit for operation after it was confirmed that they meet grid code requirements in order to reach commercial operation stage. By facilitating the integration of independent power producers into the South African grid Eskom provides a basis for a sustainable future energy system with reduced carbon emissions. The first 1000 MW consisting of 23 solar and wind projects are soon to be followed by another 2700 MW of installed capacity, scheduled for the end of 2016 (extracted from the Renewable Energy Independent Power Producer program - REIPPP). This trend is highly appreciated and will hopefully experience the necessary trust and confidence to be established as one of the main electricity sources in the South African energy mix.

Still, these sanctions will not necessarily solve the peaking problem, but rather intensify the flexibility requirements of the power grid. Due to the unreliability of wind and PV plants the power system must be able to compensate electricity excess as well as electricity deficits. Figure 3 was extracted from aforementioned "Transmission Update" and exemplary displays the power production curve of currently working 1000 GW of renewables.

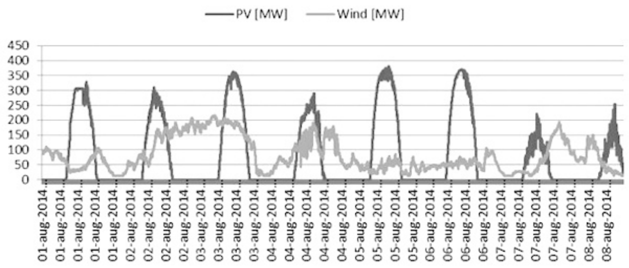


**Figure 3** Typical solar and wind electricity production profile [9].

During daytime PV is working well and gives a good contribution to South Africa's power portfolio. Wind always depends on the weather. Therefore, a reliable prediction of electricity production is almost impossible. However, both technologies can and should be used as fuel savers and emission reducers in the South African power system.

One can see, that the solar irradiation is directly linked to the electricity a PV plant is able to produce (see: dark line, figure 3 and shimmed curve, figure 2). The amount of power produced by means of wind plants is naturally non-dependent on irradiation factors. Consequently, neither wind nor photovoltaic are able to sustainably meet peak demands, what obliges them to contribute to the intermediate load.

For a closer, accurate inspection a reproduction of electricity generation on 3rd of August 2014 (from figure 3) is compared to a typical power demand curve in winter (from figure 2).

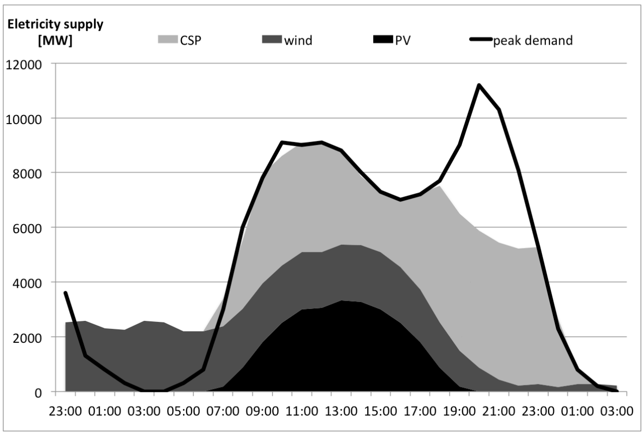


**Figure 4** Comparison of different renewables in an effort to meet peaking demands.

To show the benefits of CSP for the South African power supply system the PV and wind data is extrapolated to illustrate the predicted capacaties – mentioned in the IRP – by 2030. Obviously, the generated power by means of PV and wind will hardly meet demands, nor will it adapt the shape of the demand curve.

Nevertheless, the supply curve should adapt the demand as precisely as possible. This is where CSP with storage could prove itself beneficial. CSP exclusively offers the possibility of storing thermal energy at reasonable costs. While the sun is shining thermal energy is collected and stored in tank systems and can later be used to run a turbine in order to produce electricity when needed.

A possible CSP production curve (light grey) is added to illustrate the possibility to meet certain demand curves by producing electricity from stored thermal energy. The CSP data refers to an installed capacity of 5 $GW_{el}$ with 7.5h of storage what offers an on-demand supply of 37.5 $GWh_{el}$ during nighttime, which is a measurement from the Spanish 50 MW CSP plant Andasol 3. In reality, the benefits of CSP with storage would be even higher due to the about 50 % higher DNI in South Africa compared to Spain. On a sunny day a conventional CSP plant delivers enough energy to enable daytime electricity production while filling the storage system. Hence, meeting intermediate-load during daytime and peaking-load during morning and evening hours is possible. Furthermore, it is obvious that the CSP daytime (direct) production, providing peak-load does not use turbines to full capacity. The total amount of generated power is complemented by another 12.3 $GWh_{el}$ of intermediate-load electricity, produced during daytime. This is only a scenario and many other possibilities with already installed power plants and additional CSP plants can be made. We just wanted to show how well CSP plants fit into the South African environment and support other Renewable technologies.

## THE TECHNOLOGY

As aforementioned, CSP – in contrast to wind and PV – is able to store thermal energy (normally by means of liquid salt in a two tank system), which can later be used to meet electricity demand after sunset.

Concerning cost and energy efficiency aspects, thermal energy storage has an advantage over electrical, chemical or potential energy storage systems. Despite the technical experience wind and PV plants hold, CSP is the only established energy source with an efficient combination of energy generation and energy storage. This is what makes CSP unique and at the same time valuable for South Africa. Due to the variability it holds and the capability to supply electricity when needed it is possible to provide the necessary grid stability and flexibility, which is a requirement (as seen in figure 4) due to SA's peak demand. The dispatchable nature of the technology thus makes CSP preferable to other renewables.

A solar thermal power plant usually consists of three major components, the solar field, a conventional power block and an energy storage system. The technology can be classified into two general types of CSPs: line-focus plants and point-focus plants.

- **Parabolic trough technology** is currently the most mature technology for power plants and focuses the light on a receiver pipe (line-focus), which contains a Heat Transfer Fluid (HTF). The HTF (usually oil) is used to generate power by means of a steam turbine or to heat up the Thermal Energy Storage (TES) tank. Based on this, plants that operate with flat mirrors instead of Parabolic Troughs were recently tested. This so called Fresnel technology holds further cost reduction potential.

- **Solar towers** are the second most mature technology and use an immense number of mirrors, which concentrate the light beams onto a central receiver (point-focus), which is placed in the middle of the field. The HTF flows through the receiver, where it is heated up and can be used to generate power as well as to be stored inside the TES system.

The first two systems (line-focused and Tower) should be placed in an area with intense DNI and near grid connection. Each of the systems needs a remarkable amount of water for steam circuit operation and for keeping the reflectors clean. Current research raises an issue on dry-cooling of the turbines, which allows to cut a significant part of a plant's water consumption. The Stirling engine can be used decentralized to supply rural areas with lacking electricity infrastructure.

## PREDICTIVE SPREAD SCENARIOS

South Africa and Chile offer the best solar irradiation values worldwide and therefore hold enourmous potential for PV and CSP technologies. Still, there are several other factors, which have an impact on the profitableness of an energy source. The LCOE

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (1)$$

is an mathematical approach on illustrating the cost effectiveness of a certain power plant. It contrasts the investment expenditures $I_t$, the operation and maintenance expenditures $M_t$ and the fuel expenditures $F_t$ to the electricity $E_t$ generated over a certain time *t*. The LCOE is a central, widely accepted measurement of the costs a power plant will cause and assists on decision making, when it comes to the determination of future energy plans. At the same time the lowering of the LCOE represents a main goal of current CSP research and development.

Increasing electricity supply can be achieved by providing the power plant with a higher DNI level. Comparison of the DNI, a CSP plant receives and the amount of power it produces results in a correlation as shown in figure 5.

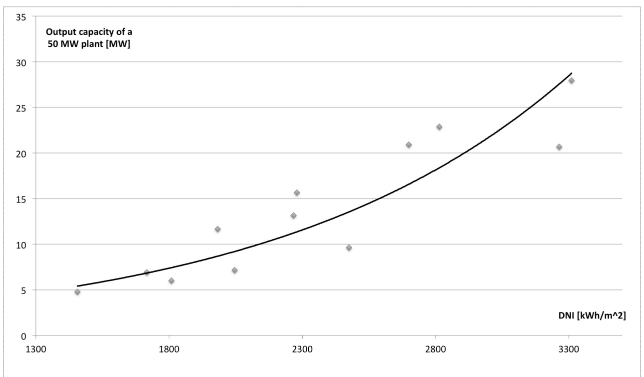


**Figure 5** Correlation between generated power and provided DNI[1] [10].

Obviously, the correlation is a disproportionately high relation between increasing DNI and generated power (see $E_t$ in formula (1)). The fact, that the figure displays a slightly bent up curve implies that the plant gains efficiency, which can be measured by $\eta = W_{out,el}/W_{in,}$ at higher DNIs. To apply this on the aim of lowering the LCOE, one can say that a suitable choice of placement in a high DNI area will lead to a lower price of electricity, as long as the costs stay the same. The high DNI of SA provides an opportunity that is almost exclusive for SA since smaller power plants are required to gain the same amount of power a bigger plant would produce i.e. in an European country. In other words, fewer reflectors are required for the same design output what results in better LCOEs.

As mentioned in the beginning CSP still has a higher LCOE than most alternative energy sources. Nonetheless, this paper states that CSP is to become a major part of the prospective South African electricity system. This statement is founded mostly on the trend, which is predicted for the future and shown in the following figures.

The LCOE forecasts for the next ten years in figure 6 are based on several studies, which analyze the cost behavior of innovative technologies, as well as the trend of fossil power resources. Furthermore, it illustrates the LCOE changes of CSP's main competitors: PV, wind and coal, throughout the past ten years.

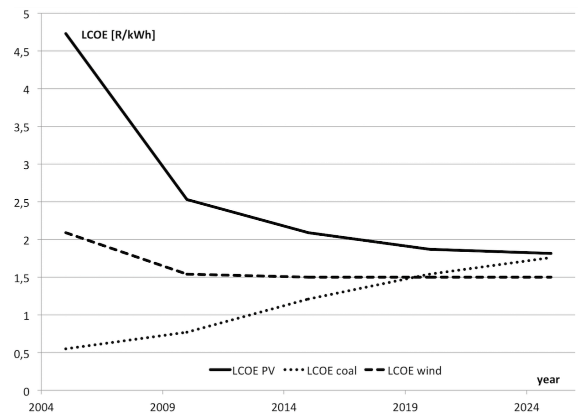


**Figure 6** Predictive LCOE trends for the next 10 years [11].

The course of the wind curve is believed to be nearly constant in the near future due to the technology's late stage of maturity. The course of the PV curve is sufficiently representative for so called "pioneer technologies", especially in the energy sector. It experiences a strong cost reduction, within the first nine to twelve years and goes through further, smaller price cuts until it reaches a continuous state, which is prescribed by environmental factors, like commodity prices and O&M costs. The wind energy sector already reached that state. The LCOE of electricity produced by means of coal is believed

[1] Data refers to the Andasol 3 parabolic trough power plant in Spain; Design output: 50 MW; Storage: salt, 7.5 hrs

to experience certain uplift, which is representative for most combustive power supplies due to decreasing fossil fuel reserves.

The dimension of this price decreasing effect on renewables depends on the investment and the confidence associated with a specific technology. If the pioneer phase – which CSP is currently in – is followed by a strong adoption phase, it will posses lower costs as it would if there were only a few investors. However, plenty attempts to predict CSP's LCOE trends have already been made. Most of them lead to results that are similar to the average trend line in figure 7.

These prognoses are based on several studies, which examine the potential of CSP in SA's future. The figure refers

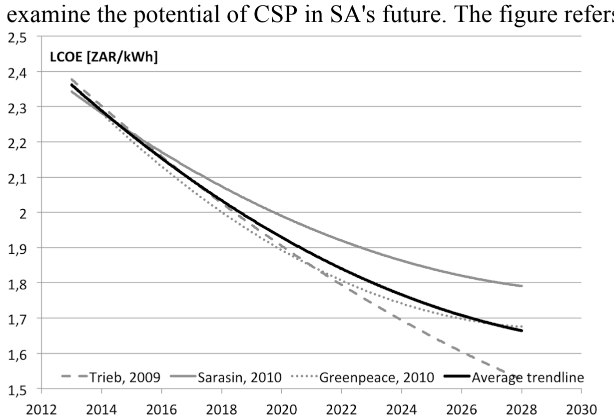


**Figure 7** Predictive LCOE trend for CSP [12].

to a DNI of 2500 to 3000 kWh/m$^2$, which can easily be reached in the northwestern region of SA. According to these studies, price cuts are motivated by the five essential cost reduction potentials, which moreover represent current main research focuses:

- Learning effects.
- Scale-up of component production
- Substitution of oil as HTF
- Alternative thermal storage technologies
- Scale-up of plant size

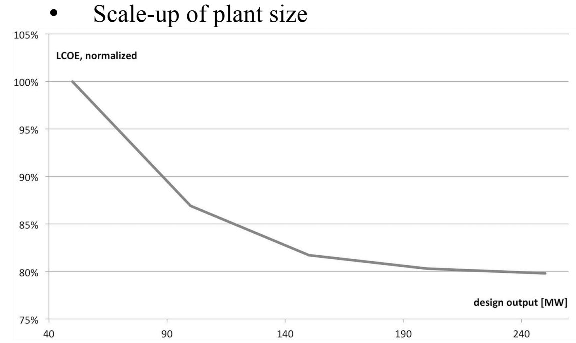


**Figure 8** CSP's LCOE as a function of design output [13].

Additionally, Fresnel technology should be mentioned. Fresnel resorts to known line-focus technologies but avails itself on a significant difference in reflector designs. The light is being concentrated onto the receiver pipe by several small mirror bars as opposed to one big parabolic trough. Each of these mirrors is tracked which entails the possibility to work with flat surface reflectors. Flat mirrors are about four times cheaper than bent ones and therefore offer yet another cost reduction potential.

A reluctant cost optimization based on the mentioned parameters could lead to an LCOE projection as shown in figure 10. As one can see the LCOE is already beneath the current peak-load level in SA, making CSP a lucrative energy source for the morning and evening hours and an immediate alternative to OCGTs. The current Renewable Energy Feed in Tariff (REFIT) provides a 3.94 ZAR/kWh reward for electricity during peak hours. This equals to 270% of the base-load tariff. Since other renewables do not provide proper energy storage possibilities, this puts CSP in a unique selling position. Consequently, this enables a financial margin, which is exclusive to CSP.

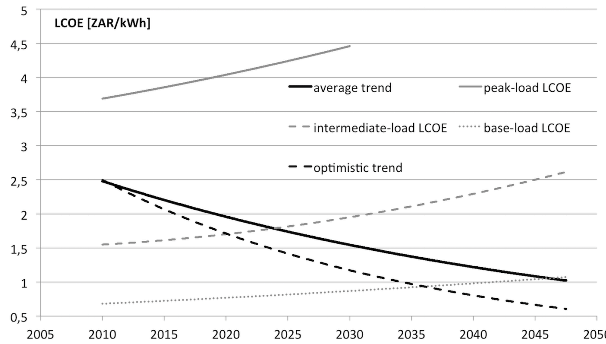


**Figure 9** LCOE prediction adapted from [14] and [15].

Furthermore, based on a conservative CSP LCOE trend (black) as shown in figure 9 (average trend) CSP will match with the intermediate load around 2025 already. As mentioned before, this prognosis could enhance with an advanced adoption phase and result in lower CSP energy costs (optimistic trend) to a cost-benefit balance in 2020. The figure is based on a SolarPACES 2013 study [14], which states that the current peaking LCOE shows a strong diesel costs dependency. The 3.69 ZAR/kWh are based on a 0% increase of diesel costs. An increase of 5% would result in a LCOE >10 ZAR/kWh. Still, as one can see the gap between CSP and OCGT costs is, even for a non-existing diesel cost increase, ≈1.4 ZAR/kWh. Therefore (based on [14]), a peak supply turn-around towards CSP technology is the next logical step for SA's energy system.

The problem about this is that the LCOE will not necessarily operate as a reliable decision-making tool. Despite the advantage in LCOE, a decision in favor of CSP goes hand in hand with heavy investment expenditures. In comparison to that, OCGTs possess low investment costs, but higher O&M costs. Still, there are adequate reasons to favor CSP with storage technology to meet peak demands. As mentioned before, independency on limited resources should be considered a critical aspect on this problem. It is difficult to give an exact prediction on diesel fuel prices, although it is certain that the costs will sooner or later experience increase. Assuming that SA decides to invest into CSP this will likely result in better LCOE values, due to the cost reduction effects mentioned above.

A decision in favor of OCGTs as peaking demand solutions would be a rather shortsighted determination, which will likely develop a predominant downside in medium- to long-term. In addition to increasing fuel costs, the opportunity costs related to market position and strategy will increase drastically. Due to natural laws of the market, an entry into a new field will continuously grow more challenging with advancing technology. In other words: the earlier a person/company/country decides to commit to a certain investment the easier it will be to overcome structural market barriers.

The British social thinker John Ruskin once said: 'An action on a certain market always and under all circumstances, results in a reaction of the markets acceptors.' This quote – made in style of Newton's third law – fits surprisingly good on today's technology market, meaning that the disappearance of a good, in this case energy, forces the ones in need of this good to guarantee it by other means. Abiding to these laws, decreasing fossil fuels will result in a market reaction trying to fill the arising supply gap. This paper states that that CSP is one of the main technologies to fill in the gap and for this reason a quick and resolute decision in favor of CSP is recommended in order to secure a good position on upcoming markets.

## CONCLUSION

Under the given peak demand of SA, CSP with storage holds a naturally high advantage for the countries' energy system and offers a good and reasonable solution to SA's electricity peak demand. This is due to its capability to store energy and supply electricity on demand. The ability of meeting peak demands, which go hand-in-hand with high costs of electricity, enables a financial incentive, which is not relevant for other energy sources.

SA has of the world's highest DNI values, which provides a lot of possible plant locations along the grid lines. Due to the good conducting performances of the SA power grid, it is possible to transport electricity with a loss of only 3% per 1000 km [16]. Therefore, this has only little impact on the choice of location. It is desirable to have good water supply and suitable infrastructure close by. Still, there are plenty of appropriate sites, especially in the northwest of SA. Placement of CSP plants holds a strong cost reduction potential and should therefore be subjected to further detailed research.

The efficiency of a power plant scales up with increasing capacity and the amount of plants built has a decreasing effect on the LCOE. In other words: The more plants are being built, the cheaper they will get. The bigger the present investment and confidence in this technology gets, the better it will develop, by financial und creditable means. Furthermore, CSP offers independency from other states as well as fossil fuel prices.

Paul Gauché suggests an addition of 3 GW of CSP to SA's energy system and states that its 'significant benefits appear to vastly outweigh the risks' [17].

All in all, CSP is a great addition to the South African energy system. Integration of this technology as peaking plants is an inevitable alternative to current OCGTs and it even holds the potential to serve on intermediate-load level within the next ten years. Consequently, this is an opportunity to the country, which must not be rejected, but rather pursued with the necessary confidence and patience.

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