EXPERT ELICITATION OF THE IMPACT OF R&D BUDGET ON CSP IN SOUTH AFRICA

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Abstract

The recent signing of outstanding power purchase agreements with renewable energy independent power producers (IPPs) by the South African government suggests the need for an increase in the funding of solar energy research, development and innovations, to encourage an improvement in the technology push. In recent years, there had been several advancements, acceptance and new patents globally which had led to the reduction in the electricity cost of majority of the renewable energy technologies. This study analyses the impact of RD&D funding on the present and future cost of electricity from concentrated solar power (CSP), as it remains more expensive in terms of cost-per-kilowatt-hour than other renewable sources like Wind or Solar PV. An extensive expert elicitation procedure was carried out due to limited data and the results from this study presents a RD&D investment strategy that will foster technological improvement and adoption of CSP in South Africa (SA). CSP in SA was evaluated, three RD&D funding scenarios were presented and analysed, and an allocation procedure was developed. The results from the study shows that strategic policies, laws and right funding can help SA to fully maximize its CSP resources potential to foster cost reduction and market viability of its solar innovations.

Keywords: Concentrating Solar Technology (CSP); RD&D budget; Expert elicitation; South Africa

1. Introduction

South Africa (SA) has been identified as one of the site with best direct normal irradiance (DNI) resources in the world, and with the level of local manufacturing capability in the county, one would think Concentrated solar power (CSP) technology would break through and be adopted as a major energy source of the future, however, recent political developments in SA have brought many uncertainties around the future of technology [1].

CSP is a type of renewable energy technology (RET) that reflects/concentrates the DNI of the sun to a receiver to generate heat that can be used for several purposes, which includes driving a turbine to generate electricity (solar thermal energy), solar water heating and air conditioning.

CSP technology is new and only few plants exist, therefore, CSP projects are still capital intensive [2], [3], but they contribute immensely to the economic growth of the host community and the nation, by creating temporary and permanent jobs and providing opportunities for improvement of local manufacturing capability [4], [5]. The electricity cost of CSP remains more expensive than other renewable sources like Wind or Solar PV and had led to reluctance a lower adoption of the technology. Solar PV has shown a huge reduction in cost over the past decade [6] and are currently able to stand alone with no need of government subsidies [7]–[9]. CSP on the other hand still have a high cost of investment which is currently around 3000 US$/kW to 8 000 US$/kW [10] and in addition to this, it requires national grid upgrade to aid electricity transportation from plant sites to where they are needed.

SA commitment to investments in research, development and demonstration (RD&D) in energy studies have been strong, and continuous calls have been made by CSP promoters to encourage more allocation to the technology in the country [11]. Investment in RD&D have often been referred as the bedrock for any technological advancement or market adoption of new technologies, however, because the public RD&D budget are often not inexhaustible, therefore, Newbery et al. [12] suggested that a balanced clean energy portfolio is required to wisely disburse the available public RD&D fund to achieve the best desired results.

This study shows the impact of RD&D expenditure on CSP technology and suggest the strategy in developing a better RD&D portfolio. An expert elicitation process was carried out with the following aims:

- to understand and analyse the current state of CSP in SA;
- to identify future potential of CSP in SA;
- to identify the major barriers, technical and non-technical, affecting the cost reduction potentials of CSP in SA; and
- to suggest a healthy RD&D investment strategy that will help overcome the barriers, and foster technological improvement and adoption of CSP in SA;

To reduce the ambiguity of the procedure, the study focused mainly on how public RD&D investment can affect the investment and electricity cost of CSP in SA.

This study presents an elicitation of the opinions of CSP experts in SA, it considered the cost evolution and the state of the technology, it analysed the SA RET RD& D budget portfolio, and it identified existing technical and non-technical barriers to CSP cost and its adoption. The results from the study eliminates uncertainties around the way forward in terms of policy decisions on CSP, by presenting a clear impact of RD&D on CSP cost in SA in such a manner that can be easily understood by policy decision makers. Thus, serving as policy instrument in determining the future funding of CSP RD&D.

2. Elicitation protocol

All the individual responses to the survey were anonymously recorded, and the experts that participated in the study cut across the academia, the industries, and national research groups (Centre for Renewable and Sustainable Energy Studies (CRSES), Solar Thermal Energy Research Group (STERG), Centre for Scientific and Industrial Research (CSIR), and South African National Energy Development Institute (SANEDI)). The study was carried out between March and July 2017. The survey was carried out via emails while the responses with inconsistencies were clarified through a one on one chat or via telephone calls. 70 emails and 9 web links were sent out but only 14 experts responded.

The questionnaire had 8 sections, and only 5 of the sections were analysed for the purpose of this paper and they are as follows:

- Expert's background, bias, knowledge of CSP technologies and policies
- State of CSP, reference data and CSP technology evaluation
- The current stage of CSP type RD&D
- Optimal SA RD&D budget portfolio
- Future cost of CSP electricity in SA based on various RD&D scenarios

In the first section of the survey, respondents were asked to evaluate their level of expertise on each of the various aspects of CSP technologies included in this questionnaire. Figure 1 showed that 7 out of the 14 respondents identified themselves as among the top experts in CSP sector of SA, 6 claimed to have a very good knowledge and only one claimed to have the basic knowledge of the technology. The highest number of expert per sector was found in the solar power towers technology in which 4 of the respondents are among the top experts in SA.

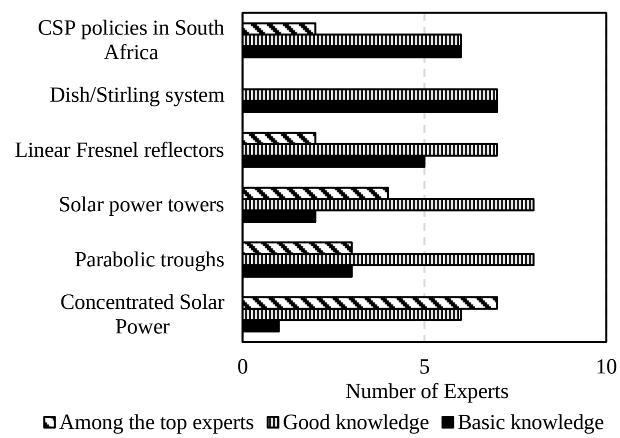

Fig. 1: Expert compositions: The degree of expertise per technology

3. CSP technology evaluation

To increase the specificity of evaluation, the CSP technology types were further divided based on the HTF and experts were asked to evaluate them base on their potentials, to identify the current maturity level of the technologies and to suggest the technological steps needed to make them achieve the identified potentials. 15 % of the experts suggested that Dish/Stirling system and Linear Fresnel (steam) might become unsuccessful if there are no urgent significant advancements in the technologies, while 22 % said the same for Linear Fresnel (molten salt) (see Figure 2). 65 % and 53 % of the experts suggested that solar power tower technology (molten salt) and parabolic trough (molten salt) respectively have the highest chance of improvement as these technology works and has room for development and advancement and were therefore suggested as the most promising of all the technologies. 50 % of the experts identified Parabolic trough (oil) as a developed technology, with an excellent status and needing only slight advances, while 23 % of the experts identified that the same technology is fully matured and may require no further improvement.

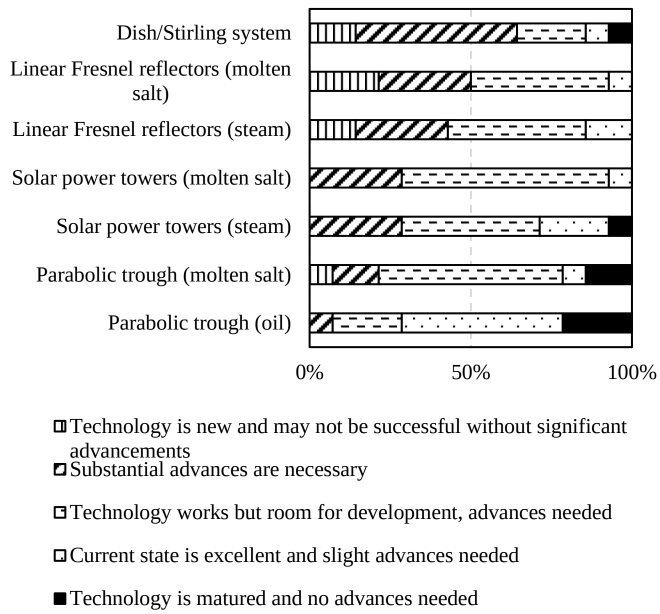

Fig 2. Current maturity stage of CSP technology types

Based on the results from Figure 2, experts were asked to specify the stage of research and development or demonstration (RD&D) that is needed to improve the types of CSP technologies considered in the survey. The RD&D was divided into stages as, basic research, engineering/applied research and demonstration. The definition of each stage of research was presented to the experts as shown in Figure 3.

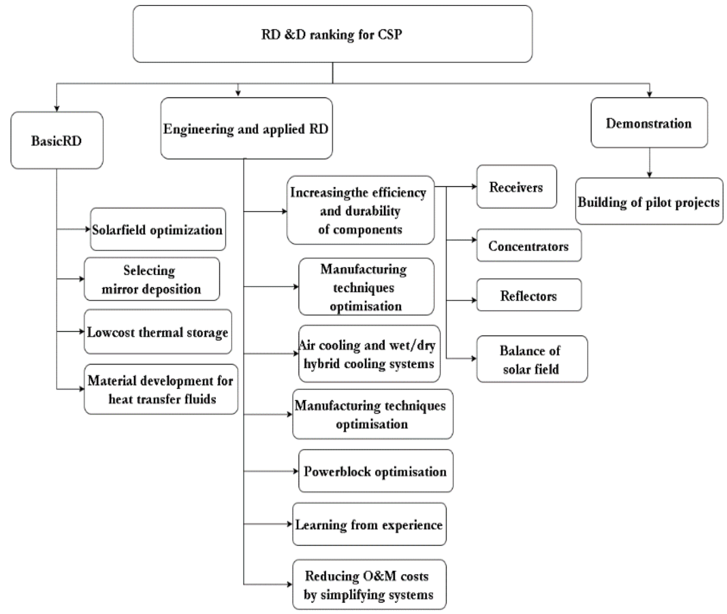

Fig 3. Classification of RD&D

Demonstration stage of RD&D in the study referred to the building of test facility to prove the technology works and could be scaled up. Also, some aspects of any of the technology could fall under the demonstration stage, if that aspect (subsystem) requires building of pilot projects before scaling up, and not necessary the whole technological part.

The responses of the experts are shown in Figure 5, where they identified Dish/Stirling system as requiring a high level of basic research to be successful, and this response agrees with the level of maturity identified earlier. Other technologies on the other hand, require high level engineering and applied RD, while majority of the experts identified that solar power tower (steam) and parabolic trough (oil) need no further demonstration, as the technologies have been tested and are fully in use. The molten salt based technology for parabolic trough, solar tower power systems and Linear Fresnel need some high-level demonstrations, and experts claim that although the technologies have been proved to work, some specific challenges needed to be overcome before scaling up. Linear Fresnel (molten salt) needs very little basic R&D, but requires demonstration sites and then high-level engineering, applied RD. Also, experts identified that Linear Fresnel (steam) needs very little demonstration as the technology works, but it requires a lot of improvement in terms of in engineering and applied RD to break through.

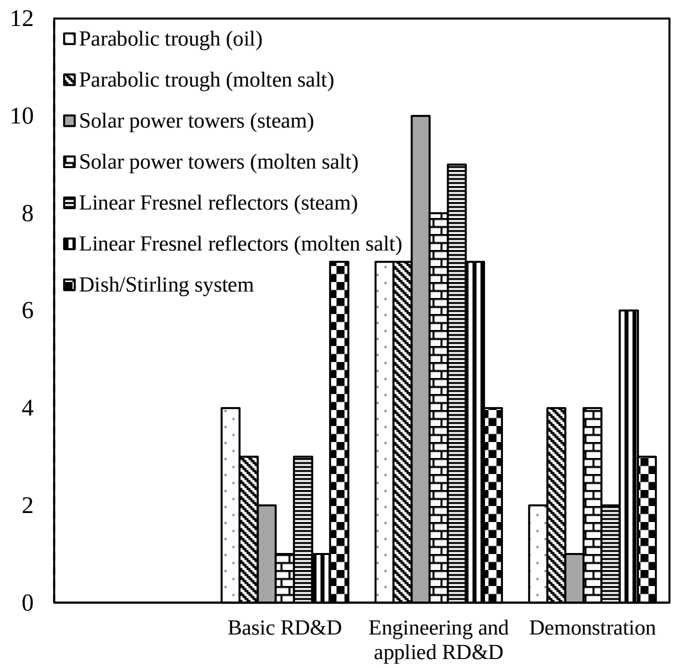

Fig 4. Stages of RD&D per technology

As seen in Figure 4, majority of the experts identified engineering and applied RD&D as the most important stage that should be concentrated on for CSP research in SA, followed by demonstration and basic research respectively. Therefore, more attention needs to be given to outdoor research, which involves development, and testing rather than basic in-house research. The need to improve the learning effect by practical demonstration was identified, and most of the experts suggested that specific CSP challenges be solved in applied research through development, demonstration, testing and optimization, with the aim of commercialization and patenting rather than simulation and paper writing.

The results from this section fairly disagree with the Wiesenthal et al. [13] reports that identified basic research as the driver of technologies, while it agrees with the expert elicitation carried out among solar energy experts in Europe by Bosetti et al. [14], where they also identified that applied research would be the major driver of solar energy technology adoption rather than basic research.

4. Allocation of RD&D fund

To present a balance mix of RD&D funding portfolio for CSP in SA, the constant sum survey approach was used. Experts were allocated 100 chips which represent the current public research budget/expenditure on CSP in SA, they were asked to allocate the chips among the various types of CSP technologies in SA as identified in the survey. Over 35 % of the experts allocated no chips (U-chips) to Dish/Stirling systems, and suggested that further major research should not be done on this technology, as its chances of success are slim. Three of the experts in this category, stated that Dish/Stirling engine is only good for academic demonstration purposes and the system has little or no realistic promising feature in terms of large scale roll out or nationwide adoption. They also noted that, further funding of this technology with the aim of commercialization, may yield no positive result and may harm the overall image of CSP.

Solar power towers received the highest chips allocation but with highest fluctuations across the budgets of all experts. While Expert 12 and 13 allocated 15 % to it, other experts gave it higher percentages, and experts 2 and 7 gave 70 % and 80 % of their budget to solar power tower respectively, thus having the largest share and the largest spread. Expert 11 on the other hand believe so strongly that more RD&D will make parabolic trough compete favourably with existing convectional power generation techniques and thus allocated 80 % of his RD&D budget to parabolic trough technology.

The fluctuations in the overall budget allocations shows the diversity of the experts' opinion on CSP technology in SA and how RD&D can help its breakthrough and adoption.

For easy comparison of budget allocations among all the experts, the overall budget allocation by the experts per each type of technology considered was calculated and presented in Figure 5.

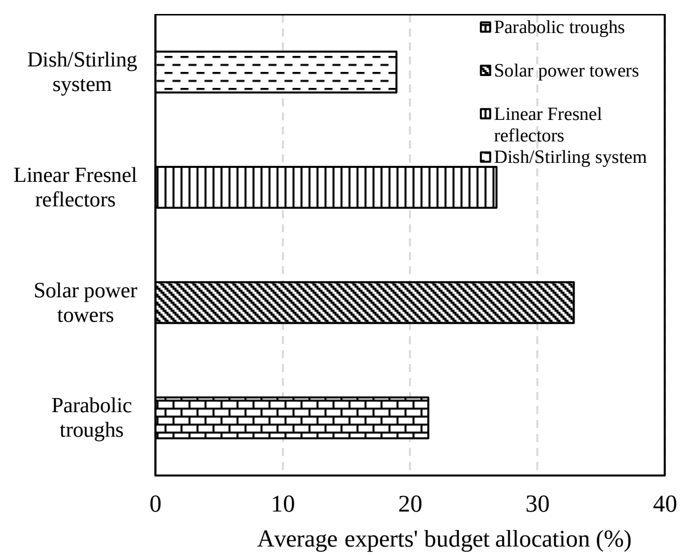

Fig 5. Average experts' budget allocation

In Figure 5, solar tower technology received approximately 33 % of the overall experts' budget in the survey, this is because all the experts believed that the technology works and that it has the highest room for improvements, in terms of its storage, capacity factor, efficiency and levelized cost of electricity (LCOE). Linear Fresnel reflectors received 27 % of the experts' budgets, because of the reduced complexities that accompanies it as compared to the solar towers. Many of the experts believe that Linear Fresnel has lower investment cost, and should this technology become successful in terms of scaling and storage, it could be the CSP champion in the future. Parabolic trough technology received 21 %, which surprisingly comes third on the average experts' ranking. Majority of the experts agree that parabolic trough is the backbone of CSP technology and that it is the most matured and currently the most competitive in terms of cost. However, some experts argued that since the learning rate of parabolic trough has not yielded any major reduction in cost over the years as compared to other RETs, it should not receive the highest RD&D funding. Conversely, other experts stated that the potentials of parabolic troughs have not been well harnessed, and more RD&D needed to be done on various aspects of the technology including heat transfer materials, energy conversion and storage, and that with breakthrough in such aspects, parabolic troughs will surely help CSP breakthrough in the ongoing battle of RET electricity cost. Dish/Stirling technology however received the lowest budget allocation as expected based on the responses from the previous sections. 19 % of the total experts' budget allocation was given to Dish/Stirling, and majority of the respondent who allocated chips to this technology are experts in the academia, who are idea and basic research enthusiasts. Some of them argue that no enough research had been done to prove that there are no feasible storage techniques for Dish/Stirling technology.

On overall the experts gave a wide range of CSP RD&D portfolio by allocating chips to the various types of technologies presented to them. While solar power tower may have received the highest average, it cannot be generalized that it should receive highest funding allocation in the CSP RD&D portfolio, because the average presented was based on the individual author's allocations. However, it can be said that solar tower, parabolic trough, and linear Fresnel received good allocation among all the experts as they identified that they have a very high potential and that more effort should be put to improve their abilities and to identify their potential market.

5. Cost analysis: the future cost of CSP based on different RD&D scenario

This section aimed to identify which scenario of RD&D funding would lead to the greatest reduction in CSP investment and electricity cost, and in this section of the survey, experts were asked to estimate their expected cost of electricity produced with CSP technologies in 2040 under the following public RD&D investment:

Scenario 1: Research in the field of CSP receives the current yearly amount of R&D (SA public RD&D expenditure)

Scenario 2: The current yearly amount of R&D expenditure in CSP increases by 25%

Scenario 3: The current yearly amount of R&D expenditure in CSP increases by 50%

Experts were given 4 ranges of cost options to estimate what the future cost of CSP electricity under the scenarios presented would be. An extra option was added to give the experts the freedom to suggest their expected cost, if it does not fall within the ranges presented to them. The results in Figure 6 shows that 50 % of the experts agreed that the current cost of CSP in SA is likely to remain unchanged if the current budget allocation RD&D in CSP does not increase. 30 % of the experts chose that the current RD&D expenditure on CSP in SA will lead to a fair reduction in electricity cost to around 8.6 c$/kWh (ZAR 1.2/kWh) (which is still less than the present day solar PV price) in the year 2040 but through a slow reduction rate.

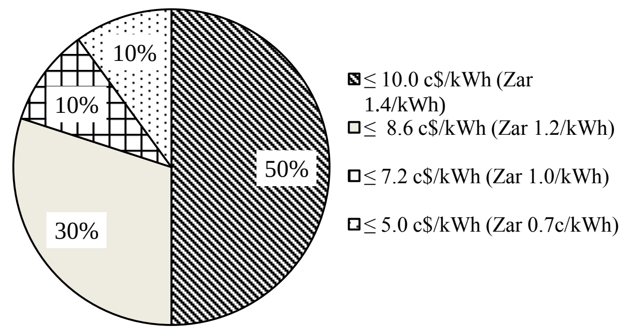

Fig 6. Future cost of CSP electricity in SA with current RD&D funding

The remaining 20 % of the experts were very optimistic that the current R&D will eventually lead to a low CSP cost of around 5.0 – 7.2 c$/kWh, stating that, effective utilization of RD&D fund plus global market force could force down the CSP cost in SA.

Scenario 2 was set to analyse what the impact of a 25 % increase in the current public RD&D would be on the cost of CSP electricity in 2040. The same range of CSP electricity cost were presented as before in scenario 1, and a drastic optimism was seen in the responses of majority of the experts as 47 % immediately proposed that the cost of CSP electricity in 2040 will be less than 7.2 c$/kWh (ZAR 1/kWh) and 35 % proposed that the cost of CSP electricity will be less than 8.6 c$/kWh but not as low as the 7 c$/kWh mark (see Figure 7). 6 % of the experts remained pessimistic about the reduction in the future cost of CSP electricity in this scenario, while the other 12 % were very ambitious and suggested a 50 % reduction in cost of CSP electricity could be achieved in this scenario, leading to CSP electricity cost of 5 c$/kWh in 2040.

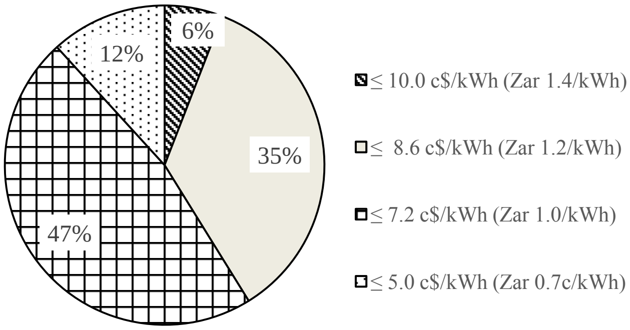

Fig 7. Future cost of CSP electricity in SA with 25 % increase to the current RD&D funding

The experts were provided with the third and most ambitious scenario, in which we aim to determine what the future cost of CSP electricity would be in the year 2040, if the current CSP public RD&D expenditure be increase by 50 %. Majority of the experts (61 %) as shown in Figure 8 assuredly said that the cost will be lower than 5 c$/kWh (ZAR 0.7c/kWh), thus will lead to maximum CSP adoption and competitiveness, while the remaining percentage was a fair mix among other costs. Conversely, it is worthy to note that, 3 experts chose that even if the CSP RD&D cost be increase by 50 %, it is not likely to yield any effect on the cost of CSP electricity. Two of these experts identified local manufacturing capabilities as a major limitation while the other identified politics and the willingness on the on the part of government as important actors in cost reduction of CSP technologies.

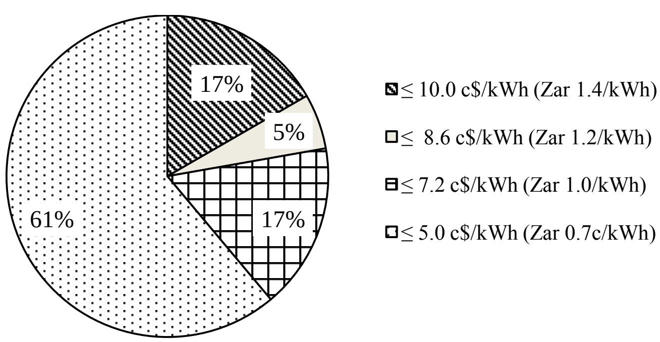

Fig 8. Future cost of CSP electricity in SA with 50 % increase to the current RD&D funding

This section showed that all experts in CSP in SA agreed that there is a direct link between RD&D and electricity cost of CSP, and that an increase in the RD&D expenditure will lead to a significant reduction in the investment and electricity cost of CSP. However, there was a huge disparity in the exact quantification of the effect, as experts 8 and 12 (see Figure 9) explained that, if the current CSP RD&D expenditure does not increase by up to 50 % or more, there would be no significant change in the electricity cost of CSP, so they only gave answers to scenario 3. Experts 3, 7, and 9 suggested that depending on the priority of the research work, cost reduction under Scenario 2 could get as low as 7 c$/kWh, but they are very sure that the cost would be lower than 8.6 c$/kWh by 2040 under such scenario. There were follow up interviews with experts whose chips were allocated inconsistently, and they explained that only an increase of 100 % or more on the RD&D expenditure on CSP would lead to flexibility of research, in which less matured technologies with higher uncertainties and the matured technologies with huge potentials, can both be improved on and developed to become better and more competitive systems. This they said would probably usher in an era of exponential cost reduction of CSP technologies.

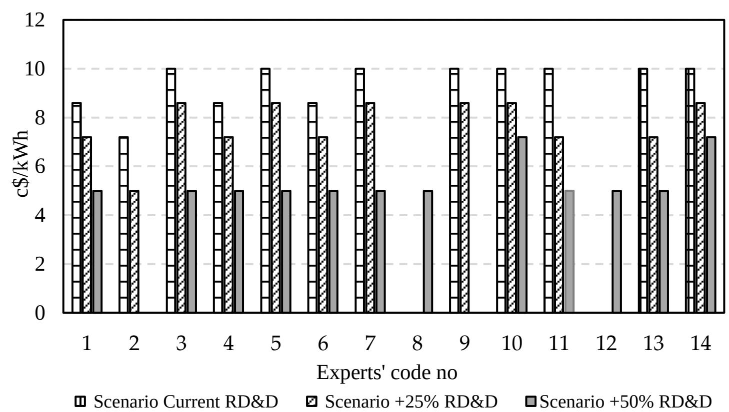

Fig 9. Variation in experts' responses

To regularize the identified inconsistencies in the experts' responses in this section, specific experts were asked what would be the minimum breakthrough cost of CSP in SA, and on average, they suggested that, any cost below the 7.0 c$/kWh (ZAR 1.0/kWh) would break through, therefore setting a threshold of ZAR 1/kWh. One specific expert said that, if this threshold costs were not achieved by year 2030, then there would be no need to build newer CSP plants, as that could be the end of the technology in SA. The follow-up questions made it easy to eliminate the unclarities in the experts' answers, while those that gave more than one cost option per scenario as identified before were asked to select their most preferred.

In summary, this section also confirms that all experts agree that the current RD&D budget may lead to no reduction in the future cost of CSP. Here, an increase of 25 % on the current public RD&D expenditure in CSP could have a cost reduction effect, but may not lead to a competitive cost (threshold cost) as it can only achieve cost reduction to between 8.6 c$/kWh and 10 c$/kWh, which is relatively higher than that present cost of some generation techniques. An increase of 50% or more on the RD&D budget could force a significant reduction in CSP cost which would further reduce the cost beyond the threshold to reach around 5.0 c$/kWh (ZAR 0.7 c/kWh).

6. CSP Diffusion possibilities

Although they contribute to the success or failure of any technology, technical and non-technical barriers as well as the level of RD&D improvement are not the only drivers of diffusion [14]. While the capability and the potential of CSP technology to break through in SA have been identified in this study, its success will also depend on the global acceptance of the technology and the interest of other nations to adopt it.

This section aimed to analyse the experts' opinion on the expected future global diffusion pattern of CSP technology. The experts were asked to specify how long it would take any innovative local CSP technology, which is developed in SA and has entered the local market to diffuse into the global market.

Experts according to this survey agreed that it will take longer time for innovations in SA to diffuse into other African countries than to the rest of the world because very few African countries have shown interest in the adoption of CSP technology over the years and the deployment of new innovative technologies in these countries will be challenging even if they adopt CSP soon (see Figure 10). The experts also identified that it will take between 5 - 10 years for most of the locally made technology to diffuse into the global market, and while innovations with good and competitive qualities may have an edge, their global diffusion will also depend on the non-technical barriers presented in the study.

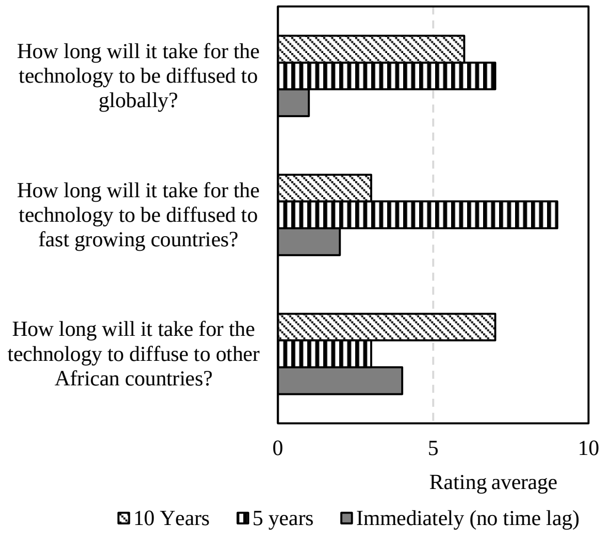

Fig. 10: Diffusion rate of CSP innovation from SA

7. Conclusions and policy recommendation

In this study, data were collected on the effect of public RD&D expenditure, an expert elicitation protocol was carried out to understand these effects and how the future of CSP in SA look like. CSP technology experts in SA commended the commitment of the DST, DoE and the government of SA to the development of RET energy sources, especially on the current RET RD&D expenditure, which makes SA one of highest contributor to a sustainable sub-Saharan Africa [15]. 86 % of the experts believe that an increase in the RD &D budget with a good partnership among academic and research institutions will lead to an improvement in the adoption of CSP technology in SA. They also suggested that RD&D should be done with the aim of commercialisation and that there is need to develop deployment strategies that will aid the fast diffusion of CSP innovation from South African institutions.

Experts also identified that, use of molten salt currently pose a lot of technical risks because it is new, while the oil technology had established itself over the years, and majority of the experts therefore suggested that more research should be done in developing better and mature molten salts HTF. This study showed that the technical challenges facing the types of CSP technologies may be similar, but the solutions must be unique, as each technology type poses unique technical risks in their advancements.

While the current cost of electricity from utility scale solar PV may be on exponential reduction, CSP currently offers better capacity factors and grid support, like its flexibility of operation and dispatchability features, which are essential characteristics for good penetration of RETs into the existing grid [16]. In the coming years, it is expected that RD&D will improve and help CSP technologies developing systems with even higher capacity factors, higher operating temperatures, improved thermal cycles and more efficient storage techniques.

There were no clear conclusions on CSP RDR&D portfolio for SA, as some experts believed that the most matured types of CSP should receive majority of the RD&D fund with lower funds given to less matured technologies, while other experts suggested the opposite. Therefore, the results from this study imply that rather than selecting one/some of the CSP types to be the technology champion(s) in SA, the various types of technologies should be allowed to compete, and the policy makers should just make sure that none of the technologies die. This is in agreement with the suggestions of Bosetti et al. [14], that suggested there is no need for selecting a technology winner when we can allow all the technology types to compete and thus encouraging speedy cost reduction.

Strategic policies, laws and funding can help any nation to fully maximize its solar resources potential to foster cost reduction and market viability of its solar innovations [17], and Braun et al. [18] showed that improved RD&D funding of CSP research had led to several new patents globally. However, it is important to note here that improved RD&D alone cannot foster adoption of any innovation, and that it must be supported with improved market competencies to ease its diffusion and the crossing of valley of death (VoD).

When the impact of current RD&D expenditure in SA on cost of CSP electricity was considered, most experts agreed that the cost may slightly drop below 9 c$/kWh (ZAR 1.26 /kWh) before year 2040 depending on the influence of the global market of CSP technology. The experts' responses show that it is very unlikely for CSP to be able compete with other technologies if the current rate of cost reduction is maintained, and thus suggest the need for an improvement in the RD &D funding. Also, increasing the scenario of increasing the RD&D expenditure on CSP in SA by 25 % was presented to the experts and their responses predict a 20 % decrease in the current cost of CSP, which could lead to an electricity cost below 8 c$/kWh (ZAR 1.12 /kWh) in 2040.

Interesting future costs of CSP were estimated by the experts when they were presented with another scenario, which the current RD&D expenditure was increased by 50 %. About 87 % of the experts agreed that the cost of CSP will drop below 0.5c$/kWh (ZAR 1/kWh) by the year 2040. Thus, showing that majority of the experts agreed that increasing the RD&D fund of CSP would make a positive impact on CSP electricity cost reduction.

In conclusion, improving on cost competitiveness of CSP and overcoming the major technical barriers will lead to an era of massive deployment of CSP in SA, while an improvement on the identified non-technical barriers will help its local and global adoption. Willingness on the part of policy makers in terms of megawatts allocations and improved strategic tariff plans will also help in the development of CSP technology. The study also suggested that African countries with good solar resources must partner each other on RD&D to encourage large scale deployments, smooth technology transfer, development of most promising components, and ease diffusion of local innovations in CSP. This study contributes to the limited literature on the impact of RD&D expenditure on cost and characteristics of CSP technology, and can be useful in preparing proposals, reports and policies as relating to RETs, solar energy, CSP as well as RD&D. Also, the results from this report can serve as a guide and policy instrument to stake holders in decision making toward CSP funding. Details and suggestion of the impact of RD&D on the technical and non-technical factors on CSP is published elsewhere.

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