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Citation: AIP Conference Proceedings **1734**, 160015 (2016); doi: 10.1063/1.4949256
View online: http://dx.doi.org/10.1063/1.4949256
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1734?ver=pdfcov
Published by the AIP Publishing

Initial Review and Analysis of the Direct Environmental Impacts of CSP in the Northern Cape, South Africa

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Abstract. The Integrated Resource Plan (IRP) of 2010 and the IRP Update provide the most recent guidance to the electricity generation future of South Africa (SA) and both plans include an increased proportion of renewable energy generation capacity. Given that SA has abundant renewable energy resource potential, this inclusion is welcome. Only 600 MW of the capacity allocated to concentrating solar power (CSP) has been committed to projects in the Northern Cape and represents roughly a fifth of the capacity that has been included in the IRP. Although CSP is particularly new in the electricity generation system of the country, the abundant solar resources of the region with annual DNI values of above 2900 kWh/m^2 across the arid Savannah and Nama-Karoo biomes offer a promising future for the development of CSP in South Africa. These areas have largely been left untouched by technological development activities and thus renewable energy projects present a variety of possible direct and indirect environmental, social and economic impacts. Environmental Impact Assessments do focus on local impacts, but given that ecological processes often extend to regional- and landscape scales, understanding this scaled context is important to the alignment of development- and conservation priorities. Given the capacities allocated to CSP for the future of SA's electricity generation system, impacts on land, air, water and biodiversity which are associated with CSP are expected to increase in distribution and the understanding thereof deems valuable already from this early point in CSP's future in SA. We provide a review of direct impacts of CSP on the natural environment and an overview of the anticipated specific significance thereof in the Northern Cape.

INTRODUCTION

An increased share of renewable energy generation capacity is welcome in South African (SA) given the country's predominant reliance on carbon-intensive coal power and its associated socio-economic and environmental challenges [1]. Both the Integrated Resource Plan (IRP) of 2010 and the IRP Update of 2013 includes greater allocation of renewable energy electricity generation capacity in SA by 2030. In addition to the arguable lighter environmental burden associated with renewable energy technologies, the diversification of the current electricity generation system is also welcomed because of maintenance backlogs, fuel expenses, geographical concentration and long build periods of Eskom's existing coal fleet [2].

Capacity allocations to renewable energy generation include 1200 MW and 3300 MW to concentrating solar power (CSP) in the 2010 IRP and IRP Update respectively, with the remaining renewable energy capacity allocated to predominantly wind- and photovoltaic power (PV) [3]. The building of these capacities is currently implemented through the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) which has concluded four bidding rounds to date with a fifth under way. Utility-scale CSP is the newest renewable energy addition to the SA electricity generation system and consequently an increase in local experience and context

SolarPACES 2015
AIP Conf. Proc. 1734, 160015-1–160015-9; doi: 10.1063/1.4949256
Published by AIP Publishing. 978-0-7354-1386-3/$30.00

learning can be expected. The current CSP workforce in SA is dominated by foreigners and relies on the experience and skills of countries such as the U.S. and Spain. The novelty of CSP, combined with its potential to serve peak electricity demand and to supply baseload [4] renders it an attractive generation technology for the South African

electricity system [2]. The motivation for focusing on CSP in this paper, however, lies in the resource potential far from the current transmission system and the arid environment within which CSP development takes places. Table 1 summarizes the capacities allocated to the various renewable energy technologies in the REIPPPP as recorded in April 2015.

TABLE 1. Total capacity allocated to renewable energy throughout Rounds 1-4 of the REIPPPP. These are projects ranging from development after announcement to being grid-connected and in operation [7].

Technology	Total (MW)[1]	Allocation remaining (MW)
Wind	2660	660
PV	1938	626
CSP	600	0
Small Hydro	19	116
Biomass	16	19
Biogas	0	60
Landfill	18	7
Total	**5037**	**1488**

[1] Presentation by Department of Energy, REIPPPP: Bid Window 4, Preferred Bidders' Announcement. 16 April 2015.

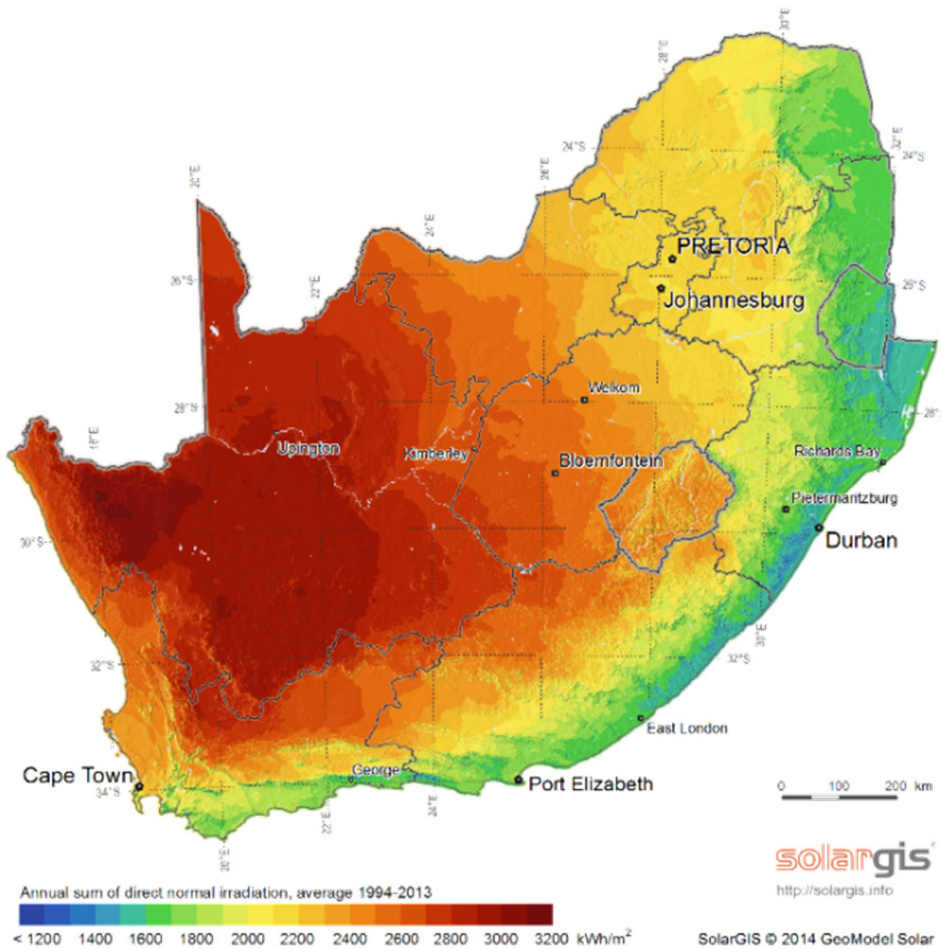


FIGURE 1. Annual Direct Normal Irradiance for South Africa [6].

Wind and photovoltaic power plants being built through the REIPPPP are distributed and largely located across the Eastern-, Western- and Northern Cape Provinces, whereas CSP plants and planned plants' location are limited to the Northern Cape [5]. Direct Normal Irradiance (DNI) levels are particularly favourable towards CSP in the Northern Cape, reaching annual values of more than 2900 kWh/m^2 [6]. Figure 1 shows the DNI values for South Africa.

At the time of writing, there is one operational CSP plant in SA, Kaxu, a 100MW parabolic trough plant near Pofadder [8], and no local or long term impact studies are available to inform optimal CSP plant design and operational procedures in the region. The lack of recorded data thus provides an opportunity to study and prepare for possibly significant future impacts of a larger fleet of CSP plants.

In addition to provincial boundaries, the biodiversity of SA is broadly categorised into nine biomes, and the two largest biomes of the Northern Cape is the Nama-Karoo and Savanna [9]. A region which overlaps with the favourable resource area for CSP in the Savanna biome, is locally referred to as the Kalahari. Current land-use of this arid region predominantly consists of agricultural- and mining related activities [10] while natural disturbances include impacts of mega herbivores, fire, frost and drought [11]. The generation and evacuation of electricity from utility-scale power plants thus provides a new suite of impacts and changes in land-use. Related work has been done on land degradation [10], land cover [12], vegetation processes [13], ecosystem services [12] and strategic environmental assessment [14], but given the recent decision to include renewable energy sources into SA's electricity generation system, studies on the environmental impact of CSP in SA is new and hard to find or absent in the literature. The environmental impacts of energy technologies can be classified as direct (e.g. water usage during operation) or indirect (e.g. metals used for component production), but also adverse (e.g. avian mortality) or beneficial (e.g. CO_2 emissions avoided), of these the direct adverse impacts are likely to be the most controversial in impact assessment reports and these are consequently the focus of this paper.

Internationally, work on the environmental impact of CSP in other forms than that of Environmental Impact Assessments (EIAs) and Life-Cycle Assessments (LCAs) of CSP has also not been well-published. In the light of development goals and other areas that are higher priority for conservation purposes, the current level of impact analysis might remain the extent of the depth of such studies, but could also become a promising future research field. Nonetheless, the matter of area-wide deployment and the contribution of other renewable energy sources, conventional- and potential unconventional energy sources further extends the necessity of longer term environmental monitoring and management. Considering the potential for CSP in SA, an investigation of the technology's impacts on the surrounding natural environment represents a reasonable starting point.

In this paper we provide an initial review of how environmental impacts of CSP is currently being assessed, a summary of these impacts based on existing literature and an overview of what the direct impact of CSP plants could be in the context of the arid regions of South Africa, which is mostly comprised of the Nama Karoo and the Kalahari within the Northern Cape.

IMPACT ASSESSMENT METHODS

The definition of impact as used in this context according to the Oxford English Dictionary is:

"***The effective action of one thing or person upon another; the effect of such action; influence; impression.***"

"***Impact assessment can be broadly defined as the prediction or estimation of the consequences of a current or proposed action.***" [15].

According to the scope of a specific EIA, the methods may differ with regards to impacts measured during different stages of a project. Projects all differ with regard to their life stages and the scale at which impacts are recorded, similarly there are likely to be impacts throughout the different stages of a power plant, *i.e.:* construction, operation and maintenance and also decommissioning. Another approach to evaluating impacts is to assess impact of different plant components (e.g. solar field, roads, heat transfer fluid) as it is done in LCAs (e.g. [16]).

Environmental Impact Assessment and Ecological Impact Assessment

Impact assessment methods are applied over various fields [15], but the specific focus of this paper is that of EIA and ecological impact assessment (EcIA) as tools and/or methods containing tools to identify direct impacts on the natural context within which CSP plants are developed.

Proper implementation of EcIA is said to provide an ecosystem management approach which is scientifically defensible and can be applied at a range of scales. Experience gained in EcIA has predominantly taken place through the application thereof as part of EIA practice. Environmental impact assessment is the broader of the two approaches that includes social and economic considerations and the potential impact which development activities may have on these. The demand for both EIA and EcIA as environmental management tools is growing as pressure on natural resources increase and biodiversity becomes more threatened [17].

Governed by law in South Africa, performing an EIA is mandatory for certain development activities as stipulated and governed by the EIA Regulations as gazetted in Government Notice No. R543 in 2010 under the National Environmental Management Act (Act no. 107 of 1998; [18]). The depth required for an EIA study depends on the proposed development activity, and can vary between a basic assessment report (BAR) and a full EIA with an environmental monitoring plan. This is determined by three Listing Notices, and according to the Listing Notice applicable to utility-scale CSP plants requires a full EIA report with environmental monitoring plan, a process that involves many stages, stakeholders and administrative details.

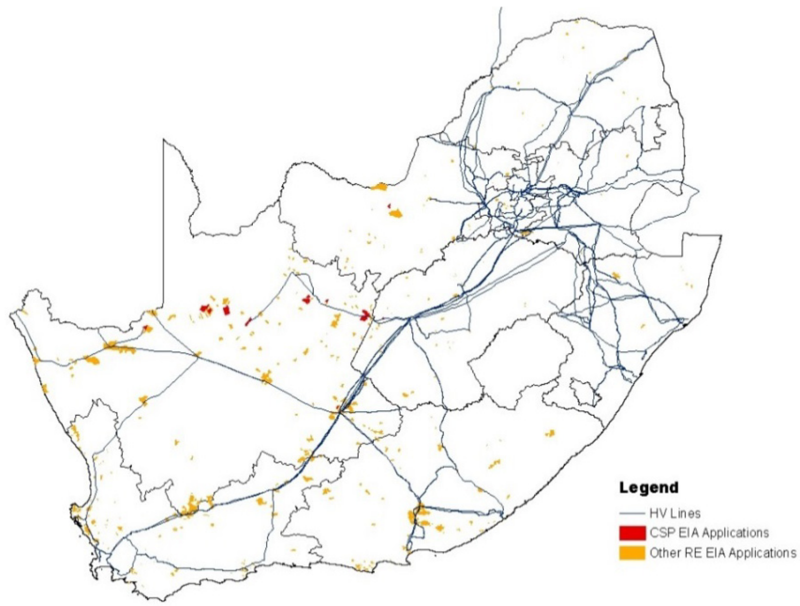


FIGURE 2. All renewable energy EIA applications received by the Department of Environmental Affairs since the start of the REIPPPP [5].

The geographical spread of possible impacts from renewable energy projects is shown in Figure 2 which represents all renewable energy EIA applications received by the Department of Environmental Affairs until May 2015 and ranges from projects that only need a BAR to those that are already in the operational phase.

Strategic Environmental Assessment

Being complementary to EIA, Strategic Environmental Assessment (SEA) can play various roles depending on which stage within a decision-making process it is being included. SEA can either be used as an assessment tool prior to a policy, plan or programme or as an evaluation tool during the formulation of a policy, plan or programme. A distinct difference between EIA and SEA, however, is that EIA highlights both negative and positive impacts while SEA is a more proactive approach where the best suited development activities and areas are matched prior to development proposals.

Two more overarching roles of an SEA are in advocating the environmental profile by giving preference to it and in integration by combining social, economic and environmental considerations. The approach to SEA is not formally determined, but is adjusted according to the intended role the SEA needs to play within specific circumstances [19].

In South Africa, a SEA was performed to determine areas where "large scale renewable energy projects would have lowest negative environmental impacts while yielding the highest possible social and economic benefit to the country". These geographical areas are named Renewable Energy Development Zones and are currently the only SEA relevant to the work discussed in this paper [20]. From a SEA that was performed for the future of the transmission grid development based on the requirements of three scenarios within the IRP, five Transmission Power Corridors were identified across SA [3].

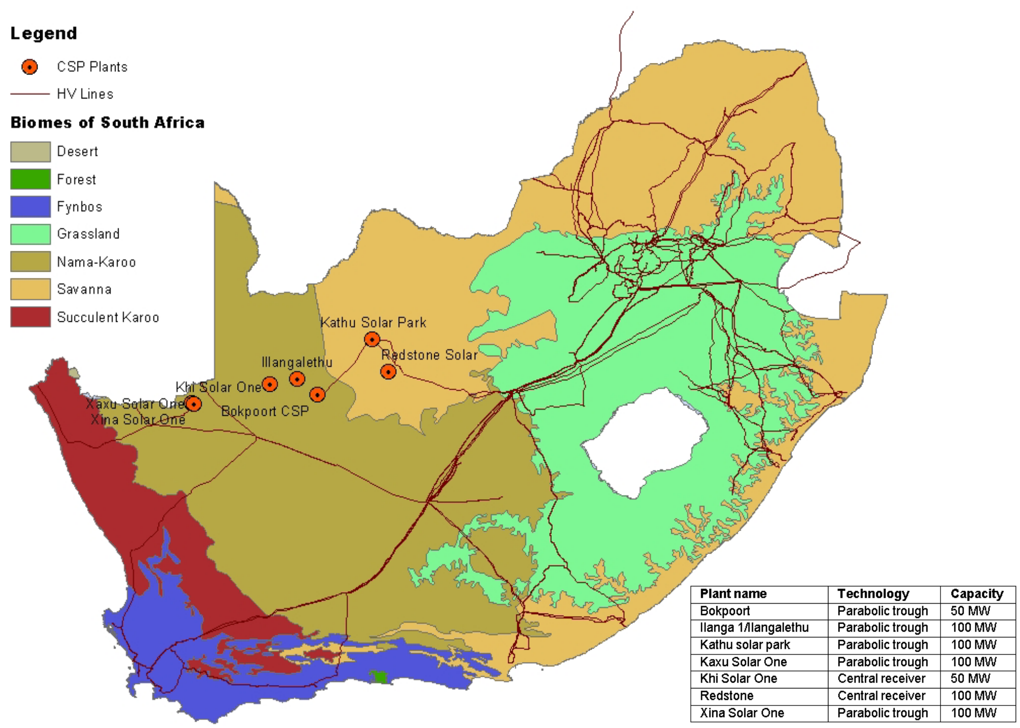
Although SEA is a higher level approach on a policy-informing level, identification of impacts on local and project level could be minimized by narrowing down according to areas most favourable with regards to infrastructure and also sensitive and/or no-go areas.

Other Assessment Methods Used for Electricity Generation Technologies

In the wake of sustainability goals and marketing opportunities, quantification of the environmental footprint of activities and products has become popular and freeware to calculate life cycle impacts and 'carbon footprints' are readily available. The methods discussed in this section generally assess and quantify indirect environmental impacts (e.g. LCA). The results from such assessments are valuable in specific instances, but do not provide opportunity to focus on the Northern Cape specifically. Hence, such indirect impacts and assessments are not the focus of this paper.

Calculating the environmental impacts of a product or process' entire life cycle is done through LCA and is also referred to as a 'cradle to grave' approach. LCA is commonly done using two broad approaches, namely process or economic-input-output LCA. The first, process-based LCA investigates the effects of all processes as well as that of disposal. Each stage of a product or process' life is assessed by calculating mass and energy flows and assigning impact factors to such flows. This bottom-up approach tends to be time and cost intensive due to analysis of indirect process flows. For economic-input-output LCA, the direct and indirect impacts from different sectors of the economy are assigned to a monetary output value. This top-down approach then aggregates the impacts from the various sectors involved in a product or process. The weakness in this method is the risk of generalization due to the categorization of economic sectors [16].

Another approach which commonly overlaps with LCA, but is widely used for electricity generation technology comparison is calculating greenhouse gas emissions per kilowatt-hour or megawatt-hour. The inverse of this approach is also sometimes used in arguments, where comparisons are made on the amount of greenhouse gas emissions that is being avoided by a certain unit of electricity generated. Avoided impacts can also be extrapolated to other environmental impacts associated with conventional electricity technology, e.g. acid mine drainage associated with coal mines [21].



Plant name	Technology	Capacity
Bokpoort	Parabolic trough	50 MW
Ilanga 1/Ilangalethu	Parabolic trough	100 MW
Kathu solar park	Parabolic trough	100 MW
Kaxu Solar One	Parabolic trough	100 MW
Khi Solar One	Central receiver	50 MW
Redstone	Central receiver	100 MW
Xina Solar One	Parabolic trough	100 MW

FIGURE 3. The Biomes of South Africa and the location of the seven committed CSP plants, all located in the Savanna (Kalahari) and Nama-Karoo Biomes [8][24].

THE NORTHERN CAPE CONTEXT

The Northern Cape has both the lowest population and the lowest rainfall in SA. The mean annual rainfall is between 100 mm and 520 mm in the Nama-Karoo and in the Savanna biome, rainfall varies between 235 mm and 1000 mm due to the biome's distribution from the tropic northeast towards the drier northwest [9]. Two towns which are close to several CSP projects, Pofadder and Upington, have mean annual rainfall values of 92.7 mm and 150.6 mm respectively [22].

Biodiversity in the Northern Cape is predominantly determined by the dry climate and is often described as a 'desert'. As mentioned earlier, the area into which CSP is being deployed, overlays that of the Nama-Karoo and Savanna biomes, where the latter is also referred to as the Kalahari. Biomes are further divided up into bioregions and then vegetation types. The vegetation types that are most common in the Northern Cape are: Bushmanland Arid Grassland, Gordonia Duneveld and Kalahari Karroid Shrubland [23].

The biomes of SA and the committed CSP plants and the associated capacities and technologies are shown in Figure 3.

ENVIRONMENTAL IMPACTS OF CONCENTRATING SOLAR POWER PLANTS

As reiterated by Hernandez *et al.* [25], work relating to the direct environmental impact of utility-scale solar energy is not common in the literature and thus provides opportunity for foundational work.

A suite of direct impacts are possible and these potential risks to the environment include: atmospheric pollution from life cycle fuel combustion, possible impact on biodiversity, water consumption, land area required, visual and audial impact, material and energy consumption and potential of a fire hazard when using synthetic oil as a heat transfer fluid [26].

Table 2 summarizes the various components of the direct natural environment and subcomponents thereof and the ecosystems across the study area and how it is likely to be impacted by CSP plants. This is high level indication and how it pertains to the specific conditions of the Northern Cape is not included, but would be invaluable in further reviews and studies.

TABLE 2. A broad summary of natural components and subcomponents likely to be impacted by CSP plants [25].

Land	Biodiversity		Air		Water	
Soil loss	**Displacement**	**Mortality**	**Abiotic changes**	**Biodiversity**	**Surface water**	**Groundwater**
Changes in land use	Avifauna	Avifauna	Greenhouse gas emissions	Birds	Usage	Usage
Changes in land cover	Invasion	Flora	Changes in albedo	Insects	Run-off	Salinization
HTF spill risk			Light & noise pollution		Biodiversity	Contamination
			Dust			

Ecosystems			
Species communities	Resilience	Disturbance	Nutrient cycling

Although the suite of CSP impacts are not expected to be uniform across the landscape for several reasons, there is value in understanding this variation in order to be better prepared for potential social-ecological challenges. Firstly, ecosystems vary according to biotic and abiotic resources across different scales. Understanding these environmental gradients and how development affects them is a long-term challenge that needs to be considered along with the social context [27]. Secondly, the technologies used are not exactly the same for each power plant. Deviations in terms of site preparation, heat transfer fluid, water usage and storage systems are basic measures on which CSP plants differ. Furthermore, different stages in a power plant's life can be expected to have different impacts on the surroundings (e.g. Hernandez *et al.* [25]), as mentioned elsewhere.

Being a water scarce country and study area, CSP makes use of dry-cooling technology which reduces the amount of water being used in comparison to wet-cooled technologies (e.g. older coal power plants) tenfold [28]. Together with the increase in demand for electricity, there is an increase in demand for water which simultaneously faces the challenge of improving quantity and quality of the country's water resources [29].

In addition to the physical and direct environmental impact of CSP plants, as well as the footprints of the roads, transmission infrastructure and substations that need to be constructed, various indirect impacts can be detected through the use of geographical information systems analysis (GIS) such as risks to certain land use types. Several GIS databases are in the public domain which relate to areas that need to be taken into account when determining land use and when planning for conservation practice. Such databases include: the South African Land Cover data, Critical Biodiversity Areas, Protected areas, Strategic Water Source Areas and also that of the SEAs as previously discussed. GIS work is thus crucial to a comprehensive understanding on the scale of impacts of CSP plants across the Northern Cape.

As highlighted above and as with other renewable energy technologies, it would be incorrect to state that there are no environmental impacts that arise from CSP plants. It is vital that the context is not left unattended to. Environmental concerns associated with electricity generation is a reality in all instances, but the externality costs of CSP is currently still regarded lower than that of almost all other electricity generating technologies [30]. The environmental benefits from using CSP is the significant reduction of CO_2 emissions against that of conventional coal power stations whilst base-load electricity can still being generated. When comparing the life cycle emissions of various renewable energy technologies; wind power, hydro power and biogas from manure show lower emissions, but this should be considered with the fact that wind power is intermittent and does not offer options for grid stability, while hydro power (when stored in reservoirs) typically has undesirable impacts on the environment [30]. Again, the novelty of the technology invites more research and investigation into the matter.

CONCLUSION

Job creation, adequate DNI levels and peak load electricity generation capability are but three aspects that make CSP attractive for the South African context, but fully understanding and managing possible environmental impacts that the technology might have in the event of major technology roll-out remains key. The long term social, economic and environmental impacts associated with renewable energy projects are still of a speculative nature in SA because of the novelty of this type of development in the country.

The scales at which CSP plants have an impact on the natural environment varies from the local footprint to landscape scale across which ecological processes and services also change and understanding this can provide insights into land management and conservation planning. Taking into account capacity allocations in policy documents such as the IRP, the number of CSP plants are expected to increase in the future which has an inevitable associated and understudied impact on the natural environment within which it will be constructed, operated and decommissioned. Valuable future work will move away from the review approach and investigate what the impacts a fleet of CSP plants is likely to have on the arid landscapes of SA by including hydrological-, land cover- and vegetation mapping. Alongside the CSP learning curve and depending on case specific impacts, research into mitigation measures would be complementary and indispensable.

There is still much room for investigating local and unique impacts within the Northern Cape and establishing methods that reflect both the value of the region's natural resources and appropriateness to suite the technology's life stages at different scales and configurations. Future steps are bound to be integrative approaches to favour both the conservation of local natural resources and technology development.

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