ENVIRONMENTAL IMPACTS OF UTILITY-SCALE SOLAR POWER IN SOUTH AFRICA: A FIRST SURVEY OF EXPERTS AND STAKEHOLDERS

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Abstract

Concentrating solar power (CSP) and photovoltaic (PV) developments are being built across South Africa's (SA) mid-western interior and the number of these developments are expected to increase according to the allocated capacities in national electricity generation plans. The majority of these developments are located in the Nama-Karoo and Savanna biomes and the environmental impacts of these developments are assessed by mandatory environmental impact assessments (EIAs) at development footprint-level. Initial findings are provided here on the environmental impacts of solar power developments currently in construction and operation stages in SA as experienced by field professionals to date. Twenty structured interviews were conducted with individuals from a number of expert groups early in 2016. The interview data used for content- and thematic analysis and four themes emerged; the results for three of these themes are presented here. The results primarily provide a first look at the most recorded impacts associated with solar power developments and provide feedback on the EIA process, which has the potential to minimize the severity of the recorded and mentioned impacts. Due to the limited experience of solar power developments in SA, the findings presented here provide a starting point for further work.

Keywords: REIPPPP; concentrating solar power; photovoltaic power; environmental impacts; interviews.

1. Introduction

The high quality of the available solar resource distributed across South Africa's north-western interior provides an opportunity to increase the contribution from CSP and PV power to the country's energy mix [1]. While slightly different in their role, spatial positioning and resource distribution, both technologies have the potential to decrease the reliance on conventional fossil energy resources and create socio-economic benefits at a national and community level [1,2].

Both the Integrated Resource Plan (IRP) of 2010 and the draft IRP Update of 2013 include allocation of these two solar power technologies as part of the total renewable energy electricity generation capacity in South Africa by 2030 [3]. Implemented through the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP), these capacities have been committed in projects throughout four bidding windows, with a fifth underway [4]. Table 1 shows the capacity allocation for both solar power technologies in the IRP of 2010, the draft IRP Update and the committed capacity in REIPPPP projects.

Technology	IRP 2010	IRP Update	REIPPPP
CSP	1200 MW	3300 MW	600 MW
PV	8400 MW	9700 MW	1899 MW

Table 1. Capacities allocated to CSP and PV power in the IRP of 2010 and the draft IRP Update [3] **and committed capacity throughout the first four bid windows of the REIPPPP** [5]**.**

To date, all CSP developments are located in the Northern Cape with the majority of PV power plants also located in the Northern Cape, but some developments are distributed across five other provinces. The locations of these projects are shown in Figure 1 [6].

Other anthropogenic activities in the country's semi-arid central region, largely representing the Nama-Karoo and Savanna biomes [7] predominantly consists of agricultural- and mining

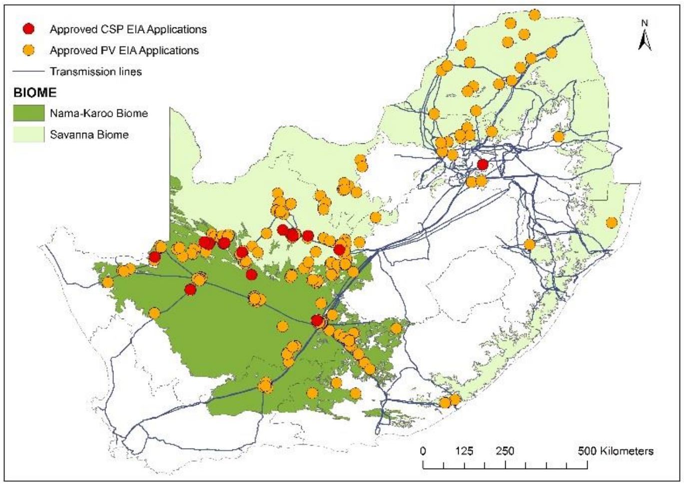

Figure 1. A map of the Nama-Karoo and Savanna biomes showing the distribution of preferred bidders for CSP and PV throughout the first three rounds of the REIPPPP with the national transmission grid. The development areas are buffered here for increased visibility.

related activities [8] while natural disturbances include impacts of fire, frost and drought [9]. The generation and evacuation of electricity from utility-scale power plants thus potentially provides a new suite of impacts and changes in the land-use of the region predominantly represented by these biomes. These impacts 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) [10], of these the direct adverse impacts are likely to be the most controversial in impact assessment reports and international reviews [11] and are therefore the focus of this paper.

The environmental impacts associated with PV developments overlap with of CSP in certain aspects (e.g. habitat transformation and dust creation during construction), but in other impact categories (e.g. impact on water resources) there is a marked difference between the technologies [12]. Due to the difference in infrastructure design and operation, there is also an inherent difference in the impact between the two deployed CSP technology types: parabolic trough plants and central receivers. The impact on biodiversity, avifauna in particular, is a primary concern related to central receiver plants which has received a wave of negative media attention [13–15]. This initial attention has in some cases been followed up with evidence based media reports [16], and studies based on monitoring at central receiver plants in the U.S. have not found supporting evidence for the alarming numbers reported in the aforementioned media wave [17,18]. Water consumption and the risks associated with the synthetic oil used as heat transfer fluid in parabolic trough plants appears to be the only significant parabolic trough-specific direct environmental impact reported in the literature [12].

The Council for Scientific and Industrial Research (CSIR) conducted a Strategic Environmental Assessment (SEA) to identify optimal geographical areas for the development of PV and wind power projects, called Renewable Energy Development Zones (REDZ). This process included resource potential, the transmission grid, environmental-, socio-economic- and land use characteristics and was intended to aid in the coordination of activities related to environmental authorisations and permits [19]. Furthermore, environmental impacts of REIPPPP projects are currently being assessed by Environmental Impact Assessments (EIAs) as regulated under the National Environmental Management Act (Act. 107 of 1998) [20]. Internationally, research on the environmental impact of CSP and PV power plants in forms other than that of EIAs and Life-Cycle Assessments (LCAs) has however, not been published extensively [10] and to the best knowledge of the authors, even less so in South Africa.

This paper represents a component of a study which investigates the direct environmental impact of solar power developments in South Africa. The scope of impacts focussed on includes all direct environmental impacts at development-footprint scale during construction and operation and excludes impacts prior to construction, during decommissioning and all socio-economic impacts. This paper, however, reports on experience and learnings of the direct environmental impacts of CSP and PV projects through interviews with individuals who have been involved in the projects which are being constructed and operated in South Africa. Not all findings of the overarching study are presented here and the aim is to include those in future publications.

2. Method

2.1. Data collection

Structured interviews were conducted from February to May 2016 with persons who have had experience with- or are knowledgeable about the EIA process in South Africa and/or the environmental impact of CSP and PV developments. Conducting interviews in-person was the preferred method, but where this was not possible, interviews were conducted via Skype or telephonically. Interviewees were at liberty to only respond to questions they are confident or comfortable with.

Criterion sampling, a purposive sampling approach [21], was used to identify individuals as candidate interviewees from certain expert groups. A minimum criterion for interviewees was knowledge of- and/or experience with the environmental impact of solar power in South Africa. Knowledge and/or experience with the EIA process in South Africa was regarded as a nonessential, but valuable criteria. From the initially identified candidate interviewees, snowball sampling [22] was also used to identify further potential interviewees.

Interviews were requested from the following expert groups as a representative sample of the greater knowledgeable and experienced population of experts [23,24]: environmental impact practitioners (EAPs), researchers, specialists, relevant government departments, state-owned utility and relevant employees of IPP developers. A total of 20 interviews was conducted, five interviewees responded to questions for both CSP and PV, an additional six responded for CSP and nine for PV. The highest relevant qualification of the interviewees were primarily in the fields of Environmental management, Geology or Geo-hydrology, Conservation Ecology and Environmental science, distributed as follows: 10% at Honours degree level, 60% at Master's degree level and 30% PhD or higher.

The number of responses which were obtained from the different expert groups for CSP and PV respectively, is summarized in Table 2. Based on experience and profession, some interviewees qualified for more than one expert group.

Expert group	**CSP**	**PV**
Research entity	2	1
State utility	1	1
Designated authority	1	1
Registered environmental assessment practitioners	2	5
Representatives from Independent Power Producers	1	1
Legislation/policy developers	1	1
Specialists	4	3

Table 2. A summary of the representation of the interviewees and the number of responses across expert groups for the two different solar power technologies.

2.2. Data analysis

Considering the appropriate sections and data obtained through the interviews, responses from interview forms were captured in Microsoft Excel or directly into the Computer Assisted Qualitative Data Analysis Software, ATLAS.ti 7 [21].

Qualitative data were subjected to content analysis by coding responses which were given for the different sections of the interview form. A combination of initial- or open coding and structural coding, as elemental coding methods were used for the first cycle coding [25]. During initial-/open coding, responses to certain sections of the interview form were selected as a 'quotation' after which a code is linked to that quotation. Second cycle coding involved the categorization of codes based on themes which were noted in open ended sections of the interview forms as well as the different topics which were intended to be addressed through the interview process. After the categorization of codes into sub-themes/categories, simple content analysis was done to lay the foundation for thematic analysis [26]. Thematic analysis involved the discussion of categories and responses/codes within categories with the highest frequency of occurrence, coding and categorization resulted in these categories being grouped into four themes.

The quantitative analysis was limited to questions in the interview form where 'yes' or 'no' were the only possible answers and to a section which required numerical ratings. In this section, ratings were obtained for 'severity' and 'physical scale' of impacts on different biophysical elements and collective impacts from distinct power plant components on the biophysical environment. Ratings were given from zero to five during the construction and operational stages of a solar power development. Table 3 shows the difference between the ratings and the associated meaning for the severity and physical scale of impacts.

Rating	**Severity of impact**	**Physical scale at which impact is incurred**
0	Interviewee unsure or regarded specific impact irrelevant	Interviewee unsure or regarded specific impact irrelevant
1	None	None
2	Light impact	Point specific (e.g. <1km radius)
3	Moderate impact	Local ecosystem (e.g. 1-20km radius)
4	Moderate-severe impact	Regional (e.g. 20-200km radius)
5	Severe impact	National (across provincial boundaries)

Table 3. An explanation of ratings attributed to the severity and scale of impacts on different biophysical elements and power plant components.

The results from this section was used to test a) for a significant difference between the rated impact during construction versus operation and b) to compare the median ratings of the different biophysical impacts and power plant components during the respective stages of the solar power development. The calculated probability values (p-values) from the Mann-Whitney U test [27] were used to test for statistical significance in the ratings between the different development stages [28]. These calculated p-values were compared with a probability level (a.k.a. alpha level) of 0.05. Results were then regarded as statistically significant when the calculated p-value was smaller than 0.05 [29]. All statistical analysis was done using the statistical plugin for Microsoft Excel, XLSTAT.

3. Results

Through the coding and analyses of the interview data from all interviewees (n=20), it was found that the responses could be summarised through the categorization of codes into four prevailing themes. Results for three of these themes are included in this paper and the fourth, which was feedback for management actions, will be presented in a future paper.

3.1. Theme 1: The direct environmental impacts from solar power developments

One of the first questions in the interview form asks if interviewees are aware of any adverse direct environmental impacts which solar power developments have on the natural environment. To this question 95% of interviewees (n=19) responded 'yes' and 5% of the interviewees (n=1) responded 'no'. Following this, interviewees were also presented with an opportunity to mention any known impacts related to solar power development. Forty-seven different impacts were coded in this section, which were then later reduced to seven biophysical impact categories. Figure 2 shows the total frequency with which the impacts within these seven biophysical impact categories were mentioned by the interviewees.

Within the abovementioned impact categories the following impact codes were recorded six times or more (frequency indicated in brackets): removal or disturbance of topsoil (6), habitat transformation or loss (16), diversion of water courses (6), impact on total water resource availability (10), impact on avifauna by towers (9), collision impact on avifauna by PV panels or heliostats (6), impact on local ecology and biodiversity (10), and visual- and dust impact (13). The codes in the aforementioned impact categories were recorded as impacts associated with solar power in general. However, four codes were recorded where interviewees mentioned impacts specifically related to CSP or PV, these were: impact on avifauna by towers, collision impact on avifauna by PV panels or heliostats, impact of confusion on avifauna by PV panels or heliostats and risk of toxic chemicals in PV panels.

The ratings which were obtained from a section in the interview form for the severity and physical scale of the impacts during construction or operation on various biophysical elements and imposed by various power plant components were recorded

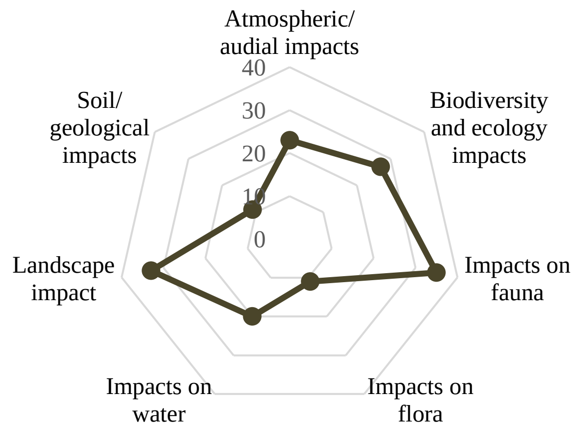

Figure 2. The frequency with which codes linked to specific impacts were recorded within the different impact categories.

separately for CSP and PV (see Table 3 for description of ratings). Several interviewees commented that ratings given here were done on the assumption that the needed management actions or plans are in place. Table 4 summarizes the biophysical elements for which significant difference between the two life-stages were found. Other biophysical elements which were included, but where no significant difference was found, are: surface water usage, surface water quality, groundwater usage, groundwater quality, insects and visual impact.

Impated biophysical element	CSP (n=10)		PV (n=13)	
	Severity	Physical scale	Severity	Physical scale
Soil	X		X	
Air quality			X	
Birdlife			X	
Mammals	X		X	
Reptiles	X		X	
Vegetation	X	X	X	
Audial impact			X	
Dust	X	X	X	

Table 4. A simplified summary indicating with an 'X' where a significant difference (p<0.05) in rating was found for the severity and physical scale of impacts between construction and operation on various biophysical elements for both CSP and PV.

The median ratings for the severity and physical scale of impacts by various power plant components were also tested for significant difference between the construction- and operation stages. Table 5 summarises those power plant components for which a significant difference was found in severity and/or physical scale of impact between the two stages. Other power plant components which were included, but no significant difference was found, are: roads, substations/power lines, evaporation ponds and balance-of-plant.

	CSP (n=10)		PV (n=13)	
Power plant component	**Severity**	**Physical scale**	**Severity**	**Physical scale**
Waterworks	X			
Power block/ inverter block		X		
Solar field			X	
Energy storage facilities		X		
Offices/ On-site accommodation			X	
Temporary structures/ scaffolding	X		X	X

Table 5. A simplified summary indicating with an 'X' where a significant difference ($p<0.05$) in rating was found for the severity and physical scale of impacts between construction and operation of various power plant components for both CSP and PV.

3.2. Theme 2: Feedback and experience with the EIA process

This theme represents feedback through the interview process where interviewees had comments regarding the EIA process and the coverage of impacts from solar power projects in EIAs. Much of the responses to this section included suggestions in which the EIA process can be amended and/or suggestions for minimizing and managing impacts, which is not included in this paper.

All interviewees were asked if they think EIAs sufficiently cover all impacts of a project on the biophysical environment, the majority of interviewees replied 'yes' (n=11) and the rest replied 'no' (n=8), with one interviewee uncertain. Some interviewees furthered their response with a comment, which was also coded and those comments which mentioned more than once are summarized in Figure 3.

Interviewees for whom it was applicable based on experience were invited to mention impacts they know of which are not covered sufficiently in the EIA process during the construction and operation stages specifically.

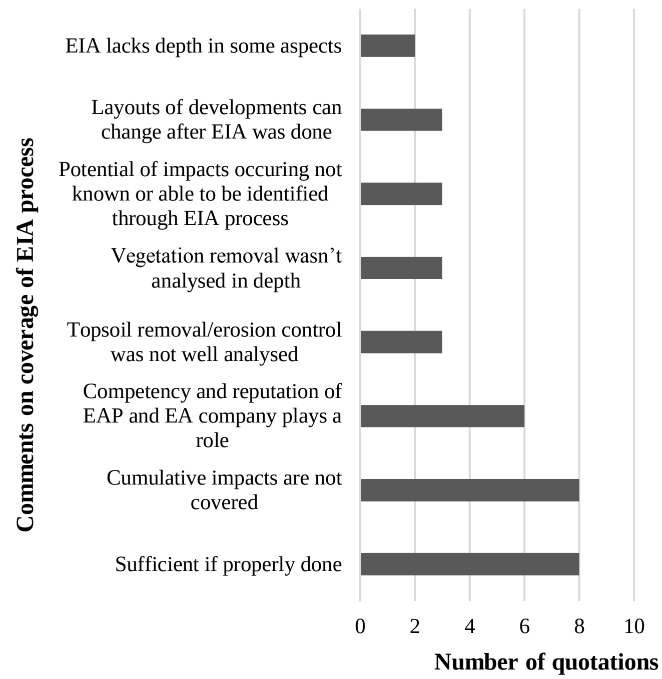

Figure 3. Summary of codes recorded in response to the question of the sufficiency of the EIA process to capture all possible environmental impacts of a project.

Five interviewees said that they think the impacts are described in detail during construction and operation and/or no impacts are omitted in the EIAs. Two respondents commented that the legislation is sufficient, but implementation thereof and the follow-through from EIA to the EMP from a legislative point of view during construction might be a weak area. An Environmental Assessment Practitioner (EAP) from the CSIR commented that "*EAPs have a good understanding of impacts, but the assessment thereof is not reinforced by site visits*". An interviewee who has experience as an EAP and as a specialist commented positively on the thoroughness of the Department of Environmental Affairs to intervene where there is a suspicion that an insufficient EIA was done. Additional impacts that were mentioned more than once are summarized in Table 6.

Construction	Operation
Impact of development layout change after EIA was completed	Cumulative impacts
Topsoil removal and erosion control not well analysed	Avifaunal collision impact with PV panels or heliostats
Vegetation removal was not well analysed	Risk of alien vegetation infestation
Hindrance to animal movement	The attraction of species to the evaporation ponds

Table 6. Impacts that were mentioned as not being sufficiently covered in the EIA process for the construction and operation phases specifically

3.3. Theme 3: Reference to the SEA process

Per occasion throughout the interview process, mention was made of the SEA which was done for PV and wind power by the CSIR. The feedback about the SEA process and the linkage to EIAs was limited to three specific observations:

- A perception that the outcomes of the first wind and solar SEA are not utilized to guide EIAs;
- A view that the usefulness of the SEA is limited given that the distribution of RE projects are in reality constrained by the existing transmission grid infrastructure;
- A suggestion that the SEA process must be improved and that CSP should also be included in the new SEA which is being done for PV and wind power.

4. Discussion

The study of public perception and acceptance of- and attitudes towards renewable energy technologies is seemingly popular in the literature [30–32], but recorded experience from professionals in the field is not as easy to find. Here the results from the three themes are discussed followed by recommendations for future work.

4.1. The relevance of the findings regarding the direct environmental impacts of solar power

Within theme 1, the most frequent recorded responses within the various impact categories are similar to the findings in a recent review paper by Hernandez et al. [11], but more elaborate than that presented about a decade earlier by Tsoutsous et al. [12]. Due to the scope of this study, the results also touch on impact categories assessed by authors who categorised impacts as beneficial, neutral, detrimental and those needing more research [10]. The impact on fauna with a particular focus on avifauna was found to be the most impact category associated with solar power developments, followed by landscape impact and impacts on biodiversity and ecology (Figure 2). The specific, most frequently recorded impacts within these categories, i.e. habitat transformation and loss, impact on total water resource availability, impact on avifauna by towers, impact on local ecology and biodiversity and visual and dust impact does not necessarily indicate that these impacts are the most significant, but it can be seen as an indication that these impacts are widely acknowledged. Due to the widely acknowledged reality of these impacts, this arguably provides an opportunity for context-specific description and management of these impacts within the ecological context of a development. An example of where this statement can become applicable is a statement by a manager of EAPs about the restricted water available from the Orange River with a similar concern expressed by an employee of Eskom. The popularly recorded impact on total water resource availability thus provides a starting point for proper description and management of this impact by CSP developments in the vicinity of the Orange River with a further question of how water extracted from the river affects ecosystems and livelihoods downstream.

The four impacts mentioned specifically relevant to CSP or PV are reflected in international studies [17,18,33], however no peer-reviewed studies have been conducted in South Africa to the best knowledge of the authors. A Master’s study done by a student from the University of Cape Town, investigated the impact of avifauna at a PV facility close to Postmasburg in the Northern Cape, but no yielded no evidence for concern regarding the link between bird mortality and PV panels [34].

The indication in Table 4 and Table 5 of the difference in rating for severity and physical scale of impacts between the construction and operation stages of solar power developments provides insight into where and when there should be a focus within environmental management plans, again considering site-specific environmental parameters.

4.2. The relevance of the findings regarding feedback on the EIA process

Under Theme 2, feedback was mostly critical, yet positive. The majority of interviewees were of the opinion that the EIA process sufficiently covers all possible impacts of a solar power development on the environment given the EIA is sufficiently executed. The two most popular comments regarding the sufficiency of the EIA process was that cumulative impacts (i.e. impacts from multiple power plants across a region) are not covered and that the sufficiency of the EIA process is influenced by the competency and reputation of the EAPs and environmental assessment company that executes the EIA. Other specific comments regarding the EIA process included a view that the requirement in the REIPPPP to complete an EIA as part of the bidding process, and the 170 day completion period risks the quality of the EIAs completed for renewable energy projects. These findings with the comments on environmental impacts recorded as not being included or sufficiently covered in the EIA process during construction and operation provide direct pointers to where the process can be refined.

An employer of an independent power developer with previous experience as an EAP described the central receiver plant, Khi Solar One, as a ‘first child’ from which many valuable lessons were learnt. This response is in line with that from an employer at the Department of Environmental affairs who openly stated that some of the impacts which might have been missed in the earlier projects' EIAs is a matter of 'learning as we go'. This links with the findings of Theme 2 in the sense that impacts which might be popular concerns or focusses at the current level of CSP and PV deployment might change as more lessons are learnt which ought to provide guidance to the interpretation of EIA reports.

4.3. The relevance of the findings regarding feedback on the SEA process

With regards to the feedback received on the SEA process demonstrated for wind and PV power, the authors elaborate here in basic agreement with these findings. After a basic spatial comparison of the location of PV development distributions built through the first three rounds of the REIPPPP in comparison with the identified REDZ, it was found that only 15% of approved PV developments are located within a REDZ. In contrast to EIAs which are a legislative requirement, the findings of a SEA are not enforceable and are primarily to guide development. These two arguments with the feedback on the SEA process and according to Therivel [35], the ultimate aim of a SEA is "*to help protect the environment and promote sustainability*". Nonetheles, taking into account feedback with relation to the adherence to the outcomes of the SEA and the three points of feedback on SEA results in a question of the usefulness of an SEA in fulfilling its aim. Furthermore, it is unclear why CSP was not included in the SEA by the CSIR, and this was also unclear to interviewees who commented on this matter.

4.2. Recommendations for future work

In the words of Johnny Saldaña [36], "*Quantitative analysis calculates the mean. Qualitative analysis calculates meaning*". In this particular field of study of environmental impacts this statement and has validity. Social inquiry has further value to assess and investigate the dynamic relationship between solar developments, technology types, the associated environmental impact and the people who guide the various processes. It would thus be valuable to improve the interview process of this study to better harness valuable information from such inquiry. The importance of making impact-data collected at constructed and operated solar power plants publically available, should however be repeatedly stressed.

The following points would be useful to consider in future studies of similar nature:

- The interview form needs to be designed with minimal room for interpretation error and a substantial pilot study could assist with this;
- A larger sample size would make it possible to evaluate the feedback of interviewees from different expert groups;
- A focus on a specific expert group has the potential to yield more specific information in case needed;
- Interviews in conjunction with case studies and impact-related data collected from specific power plants would increase the understanding of the results in practice;
- Collaboration between specialists e.g. social scientists, ecologists, economists, would extract optimal value if the aim is to take research lessons to policy-makers.

5. Conclusion

The findings of this paper suggests that although there are several known adverse direct environmental impacts associated with solar power developments, these can be managed with sufficient and competent execution of EIAs followed by customized environmental management plans. However, cumulative impacts need to be monitored and strategically planned for in order to stay within acceptable levels of habitat transformation and biodiversity impact across the landscape. The early findings presented here indicate that valuable lessons are being learnt about the environmental impacts of solar power developments in South Africa which should inspire future monitoring and research. In retrospect it appears that the interview process is useful to gather data on the knowledge of impacts and how to manage it, but research which involves the collection of ecological data would yield better results on the actual significance of the impacts mentioned in interviews.

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