Investigating the direct environmental impacts of emerging solar power and shale gas developments in two arid biomes of South Africa

by
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DECLARATION

By submitting this thesis/dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

South Africa's energy system diversification involves the inclusion of a variety of energy resources as alternatives to coal. Amongst these energy technologies supported by various policy documents, alternatives include concentrating solar power (CSP), photovoltaic power (PV) and shale gas.

Solar power developments are predominantly located across the north-western interior of the country, coinciding with the distribution of the Nama-Karoo and Savanna biomes. The environmental impacts of individual solar power projects are currently being assessed by Environmental Impact Assessments (EIAs). The area for which shale gas exploration rights applications have been received slightly overlaps with the area for which solar power projects are being deployed. No shale gas exploration activities have as yet commenced, and the size of its resource in the Karoo Basin is still undetermined. Should the resource size be economically viable, shale gas development activities are expected to start and will require EIAs.

Due to the relative novelty of these energy developments (*i.e.*, solar power and shale gas) in South Africa, local peer reviewed literature based on experience-based impact data is largely absent. The objective of this thesis is to determine and investigate the direct environmental impacts resulting from these alternative energy developments across the landscapes of the Nama-Karoo and Savanna biomes. A mixed-method approach was followed.

Structured interviews were conducted with selected expert groups and included questions on direct environmental impact from developments, the EIA process and management of impacts. The results from the interview process were coded, grouped into themes and then thematically analysed. With slight differences for the two solar technologies, interview findings indicated that habitat transformation, the impact on avifauna and cumulative impacts are major concerns related to solar power development. These findings were supported by site visits, which provided an on-the-ground perspective of the impact experience from solar power plants. Shale gas interview findings indicated that all aspects of water related impacts are of very high concern. The widespread nature of shale gas developments are expected to cause distributed and repeated impacts to the landscape, especially during the production stage of development. The cumulative nature of these impacts and the uncertainty regarding baseline conditions in the Nama-Karoo were highlighted as key concerns. Simple spatial analysis was used to assess the footprints of solar power and shale gas development relative to other land uses in the study area. It was found that the current and expected footprint of future solar power development is relatively low. The exact locations for potential shale gas activities are still unknown, but given the distributed nature thereof, a notable proportion of the Nama-Karoo surface area is expected to be transformed if or when activities commence.

The management of- and strategic planning for environmental impacts of energy developments in the arid biomes of South Africa have been highlighted as critical and in need of effective coordination. This thesis provides an initial identification of the direct environmental impacts of energy developments in two arid biomes of South Africa, and a number of recommendations are made for future work.

OPSOMMING

Die diversifisering van Suid-Afrika se energiesisteem behels die insluiting van ŉ verskeidenheid energie hulpbronne as alternatiewe tot steenkool. Van hierdie energietegnologieë wat ondersteun word deur verskeie beleidsdokumente, word gekonsentreerede sonkrag (GSK), fotovoltaïese krag (FK) en skalie gas as alternatiewe ingesluit.

Sonkragontwikkelinge is meestal geleë oor die noord-westelike binneland van die land, wat ook ooreenstem met die verspreiding van die Nama-Karoo en Savanna biome. Die omgewingsimpakte van individuele sonkragprojekte word tans geassesseer deur middel van Omgewingsimpakstudies (OISs). Die area waarvoor skaliegaseksplorasiereg-aansoeke ontvang is, oorkruis gedeeldelik met die areas waar sonkragprojekte ontplooi word. Geen skaliegaseksplorasie-aktiwiteite het al begin nie, en die grootte van die hulpbron in die Karoo Kom is steeds onbepaald. Skaliegasontwikkelingsaktiwiteite word verwag om te begin en sal ook OISs benodig sodra die hulpbrongrootte ekonomies vatbaar bevind word.

As gevolg van die relatiewe nuutheid van hierdie energieontwikkelinge (m.a.w. sonkrag en skaliegas) in Suid-Afrika, is literatuur wat gebaseer is op ondervinding-verwante impakte merendeels afwesig. Die doel van hierdie tesis is om die direkte omgewingsimpakte verwant aan bogenoemde alternatiewe energieontwikkelinge in die Nama-Karoo en Savanna biome te bepaal en ondersoek. ŉ Gemengde-metode benadering was gevolg.

Gestruktureerde onderhoude was gevoer met geselekteerde kennergroepe en het vrae ingesluit aangaande die direkte omgewingsimpakte van ontwikkelinge, die OIS proses en die bestuur van impakte. Die resultate van die onderhoudsproses was gekodeer en daarna tematies geanaliseer nadat die bevindinge in temas gegroepeer was. Met effense verskille tussen die twee sonkragtegnologieë het die onderhoudsresultate aangedui dat habitat transformasie, die impak op *avifauna* en kumulatiewe impakte die beduidendste bekommernisse is m.b.t. sonkragontwikkeling. Hierdie bevindinge was ondersteun deur besoeke af te lewer aan ses sonkragstasies wat praktiese insig gelewer het rakende die impak-ondervinding van sonkragstasies in Suid-Afrika tot op hede. Die onderhoudsbevindinge vir skalie gas het aangedui dat alle aspekte van water-verwante impakte besondere kommer inhou. Die wydverspreide aard van skaliegasontwikkelinge word verwag om verspreide en herhaalde impakte in die landskap te veroorsaak, veral gedurende die produksiestadium van ontwikkeling. Die kumulatiewe aard van hierdie impakte en die onsekerheid rakende die pre-ontwikkeling toestand in die Nama-Karoo was ook uitgewys as ŉ rede vir kommer. Basiese ruimtelike analise was gebruik om die ontwikkelingsareas van sonkrag en skaliegas relatief tot ander grondgebruike in die studie area te assesseer. Dit was bevind dat die huidige en verwagte ontwikkelingsarea van sonkrag relatief laag is. Die presiese ligging van skaliegasaktiwiteite is steeds onbekend, maar gegewe die wydverspreide aard daarvan word dit verwag dat ŉ noemenswaardige gedeelte van die Nama-Karoo oppervlakarea getransformeer sal word indien of wanneer skaliegasontwikkeling begin.

Die bestuur van- en strategiese beplanning van omgewingsimpakte van energie ontwikkelinge in die dorre biome van Suid-Afrika was verder uitgewys as baie belangrik en benodig effektiewe koördinasie. Hierdie tesis verskaf ŉ aanvanklike identifisering van die direkte omgewingsimpakte verwant aan energieontwikkelinge in twee dorre biome van Suid-Afrika en ŉ paar aanbevelings word gemaak vir toekomstige navorsing.

DEDICATION

Vir my ouers wat my die geleentheid gegee het om op ‘n plaas groot te word.

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ACRONYMNS AND ABBREVIATIONS

BLSA	BirdLife South Africa
CO_2	Carbon dioxide
CSIR	Council of Scientific and Industrial Research
CSP	Concentrating solar power
DEA	Department of Environmental Affairs
DOE	Department of Energy
EAP	Environmental Assessment Practitioner
ECO	Environmental Control Officer
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
EMS	Environmental Management System
ESKOM	Electricity Supply Commission
GHG	Greenhouse gas
GIP	Gas-in-place
GIS	Geographical Information System
HTF	Heat transfer fluid
IBA	Important Bird Area
IEP	Integrated Energy Plan
IPP	Independent Power Producer
IRP	Integrated Resource Plan
KARIN	Karoo Research Initiative
kWh	Kilowatt hour
LCA	Life cycle assessment
MW	Megawatt
MWh	Megawatt-hour
NEMA	National Environmental Management Act
NDP	National Development Plan
NPAES	National Protected Area Expansion Strategy
NORMS	Naturally occurring radioactive materials
PV	Photovoltaic

REDZ	Renewable Energy Development Zones
REIPPPP	Renewable Energy Independent Power Producers Procurement Program
RSA	Republic of South Africa
SEA	Strategic Environmental Assessment
SEASGD	Strategic Environmental Assessment for Shale Gas Development
Tcf	Trillion cubic feet
TES	Thermal energy storage
VEC	Valued ecosystem component
WWF-SA	World Wide Fund for Nature South Africa

DEFINITIONS

Alternative energy	The umbrella term 'alternative energy' refers to energy sources intended to reduce undesired consequences from the energy source(s) it replaces, this thus includes both renewable and petroleum energy sources considered to replace other resources (Spellman 2012).
Base load	The minimum amount of electric power delivered or required over a given period of time at a steady rate (US EIA n.d.). Usually given in MW demand over 24 hours.
Biome	A broad ecological unit having similar vegetation structure and exposed to similar macroclimatic patterns, often linked to characteristic levels of disturbance such as grazing and fire (Mucina & Rutherford 2006; Low & Rebelo 1998).
Development footprint	Used to refer to the direct area being affected by a solar power plant or shale gas well pad. Does not include peripheral infrastructure such as roads, power lines and gas infrastructure.
Direct impact	Impact on the natural environment directly from the construction or operational activities of a power plant/drill pad. This includes possible socio-economic impacts, but not impacts before construction or after a power plant/drill pad is decommissioned.
Ecosystem service	The conditions and processes through which natural ecosystems, and the species that live within them, sustain and fulfil human life (Daily 1997).
Electricity generation system	All power plants and generators typically in a transmission-connected system and controlled by a utility company. In this case, this is mostly the South African electricity grid.
Energy	In the context of this thesis, 'energy' refers to the conversion and use of the potential from various resources for society's need, e.g., electricity generated for domestic or industrial need.
Energy mix	The collection of resources which contribute to the consumable energy supply in a geographic region. Also referred to as the 'energy diversification plan' where used to refer to increased contribution from alternative energy sources.
Energy technology	A specific set of technological skills and physical components that contribute to the energy supply system.

Energy system	The broader energy system incorporating the electricity generation system, energy resource extraction from all sources, production, storage, transmission, distribution, transportation and heating.
Exploration right areas	Areas across the Northern, Eastern and Western Cape where applications for shale gas exploration rights have been received from Shell, Bundu and Falcon oil and gas.
Hydraulic fracturing	Fracturing of deep geological formations with pressurised fluid (CSIR 2015). A technique used to prepare a gas well for production. Together with the other stages of shale gas development also referred to as 'fracking' in public domain. Due to its emotive use and unclear definition in the public domain, 'fracking' is not used in this thesis.
Impact	The effective action of one thing or person on another; the effect of such action; influence; impression (Oxford English Dictionary 2016). Here with specific reference to that of solar power and shale gas development directly on the natural environment
Land use	The arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO 1999).
Renewable energy resources	Energy resources that are naturally replenishing. These include sources considered renewable or sustainable energy resources considered inexhaustible over a 'short/human' time period (as opposed to geological time periods), but limited in the amount of energy that is available per unit of time.
Shale gas	The natural gas produced from shale formations. Shale is a fine-grained, sedimentary rock composed of mud from flakes of clay minerals and tiny fragments (silt-sized particles) of other materials. The shale acts as both the source and reservoir for the natural gas (CSIR 2015).
Shale gas development	The exploration, construction and production activities related to shale gas. This covers the entire life cycle up to and including eventual closure of facilities and restoration of the sites (CSIR 2015).
Solar power	Broadly refers to the converted energy from the sun to usable electrical power; not referring to the use of any specific technology to do so.
Solar power development	Used to collectively refer to all infrastructure and activities related to multiple solar power plants.
Sub-station	Facilities forming part of the national transmission network where electricity is fed into/contributed to the grid or distributed to electricity

	demand-areas. Sizes of sub-stations vary according to the location and voltage associated with the incoming and outgoing transmission lines.
Transmission infrastructure	An interconnected group of electric transmission lines and associated equipment for moving or transferring electric energy in bulk between points of supply and demand. The transmission system breaks into the distribution system near the points where the electricity is used. Also referred to as 'transmission grid' or just 'grid.'
Utility-scale	The generation by electric systems engaged in selling electric energy to the public through a corporation, person, agency, authority, or other legal entity (*i.e.,* Eskom in SA) (CSIR 2015). Typically forms a network of large power plants or facilities.
Vegetation type	The work of Mucina and Rutherford (2006) which groups South Africa, Lesotho and Swaziland's flora into 440 types grouped per biome. This represents the National Vegetation Map; it is also available as GIS database.

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CHAPTER 1: INTRODUCTION

"*Energy is not an end in itself. The fundamental goals we should have in mind are a healthy economy and a healthy environment*."

- Richard Balzhiser, former president of Electric Power Institute

South Africa is implementing diverse energy sources to be used in the country by including alternatives to coal, the current primary energy resource. Consequently, the landscape within the country's arid interior is becoming exposed to an increasing number of new energy developments, such as solar power projects and shale gas exploration. Such developments in the context of forecasted growth rates can be considered a potential inflection point, marking the start of more energy developments in specific biomes. The environmental impacts of solar developments are currently not well understood but are being evaluated by means of project level assessments. Although shale gas activities have not begun, the potential impacts of these developments are being studied strategically based on assumptions of a viable local shale gas resource. This chapter initiates the first known investigation into adverse direct environmental impacts associated with these current and prospective developments with respect to their locations in the Nama-Karoo and Savanna biomes.

1.1. Background

1.1.1. Energy and the natural environment

Energy is essential to the survival and well-being of society. In more specific examples, energy development has impacts related to land use (Dale et al. 2011), socio-economic advancement (NPC 2012) and determining pathways of further development (Scholvin 2014). Policy development is needed to guide energy technology deployment in energy systems and is viewed as multidisciplinary as it is linked to social and environmental sciences, among others (Falkner 2014). Studying this relationship between energy and other sciences and social sectors is considered increasingly important, especially with a transition towards sustainable development (Akella et al. 2009).

Awareness and guidelines with reference to the impact of development, and energy production as the driver for development, have steadily increased since the 1970's. The focus on greenhouse gas emissions and other contributing factors to climate change has also increased during this time (Dincer 1997). As a consequence, power generation from renewable sources is globally deployed in an effort to assist in the reduction of activities contributing to climate change, decrease reliance on finite fossil resources and move towards sustainable development (e.g., Lund 2007; Boyle 2012). One broad definition of renewable energy is "*energy obtained from the continuous or repetitive currents of energy recurring in the natural environment*" (Twidell & Weir 1986).

The sun is the primary source of almost all utilised energy sources, with the exception of geothermal and tidal energy. Keeping in mind that only 70% of the solar energy arriving on earth is available for use, the amount of energy received from the sun annually is still about 7600 times more than the total human consumption of energy from all sources, according to energy usage in 2009 (Boyle 2012a). Although only a basic comparison, it highlights the magnitude of energy flow to- and on earth from year-to-year, impacting an immense diversity of life and essential to it.

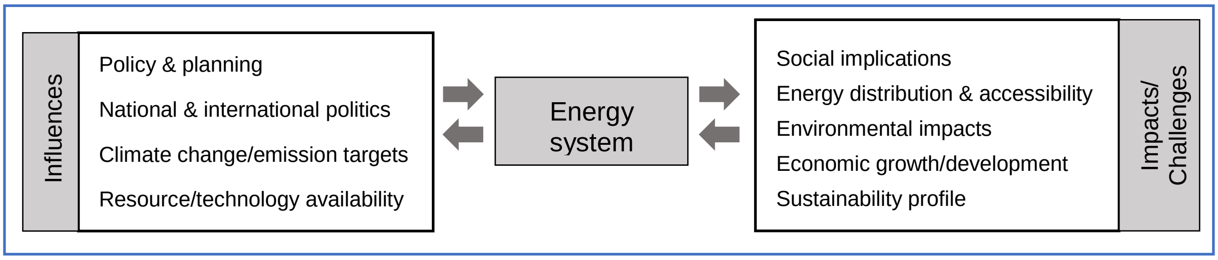
1.1.2. Current energy system and future energy plans in South Africa

South Africa's past and current energy system has involved planning and implementation embedded within an increasingly intricate context. The past and current status of this system has been influenced at international and national policy levels throughout the value chain to the end-user and end-use technology manufacturer (Baker et al. 2014). These relationships and influences are not restricted to a certain economic sector but play a role in the private sector, public enterprises, research and development, and various government departments (e.g., Department of Energy, Department of Science and Technology, Department of Agriculture) (NPC 2012; Pollet et al. 2015).

Energy policies and plans, economic development, resource availability and physical feasibility are amongst the overarching factors that have an impact on the country's energy future, despite past and current challenges (Pollet et al. 2015). Sustainability issues related to the environmental impact of electricity generation are mostly comprised of water usage and -pollution, air pollution and land use change, which may lead to habitat destruction at varying scales (Dincer 1997).

Apart from challenges related to energy sector planning, South Africa's current system is facing specific practical challenges. The most pressing challenges include inadequate generation capacity, continued reliance on coal for roughly 90% of electricity generation (which is directly responsible for high CO_2 emissions), and an aging fleet of power stations. Furthermore, socio-economic ramifications of the long-term environmental impacts, inadequate generation capacity and an increasing electricity tariff are the main challenges stemming from the country's energy system (Scholvin 2014). According to this description of interdependent factors and challenges, one may view an energy system as being in constant flux due to influences from various sources and impacts on various subjects similar to that of an ecosystem. This dynamic system to which several influences and role-players contribute is summarised in Figure 1.1.

Figure 1.1 A simplified illustration of the dynamics in energy systems.



The legacy of coal as the primary energy supplier in South Africa's energy system is still evident in the fleet of coal power stations owned by the national utility, Eskom (Eskom 2011; DOE 2013b). Reflecting the reliance on predominantly two fossil resources, coal and oil, Table 1.1 shows the contribution of various resources to the country's total energy supply.

Table 1.1 The percentage contribution to South Africa's total primary energy supply by various resources (BP 2015).

Source	Percentage of total primary energy supply
Coal	70.59%
Oil	22.97%
Gas	2.91%
Nuclear	2.87%
Solar	0.21%
Hydro	0.20%
Wind	0.19%
Other renewables	0.05%

The above-mentioned characteristics of South Africa's energy system and the notable reliance on fossil fuels contribute to the country's need to diversify its energy resources. Renewable energy as well as unconventional fossil resources such as shale gas are being considered in this regard. As 'cleaner', more sustainable alternatives, the abundant availability of solar resources in particular offers much potential for the future of the South African energy system (e.g., Grobbelaar et al. 2014). The best areas in South Africa for solar power generation production are in the north-western part of the country, but the majority of South Africa's arid regions are considered to have economically viable solar potential (GeoModel Solar 2014; IRENA 2012). In addition, the planned shale gas developments are located in the central southern region of the Karoo. The distribution of these developments overlap to a certain extent and are predominantly focussed in the Nama-Karoo and Savanna biomes (see Figure 1.2). Both locations for the developments of these two energy resources are arid biomes, and the inclusion of both resources in the country's energy diversification plan motivates this thesis to investigate the impact of the two solar technologies and shale gas production in the aforementioned biomes.

The Integrated Resource Plan (IRP), first promulgated in March 2011, is the official plan for South Africa's electricity generation system. The purpose of the IRP is to specifically plan for the provision of electricity from a variety of energy sources (DOE 2011). The IRP of 2010 (IRP2010) was updated in draft format in 2013 (IRP Update) but has not been promulgated. The IRP is intended to be a 'living' plan with recommended updates every two years. The IRP Update (as with the IRP2010) indicates the different capacities allocated to various energy technologies that are to be added to the country's electricity generation system until 2030. The IRP Update includes an increase in solar power and open cycle gas turbines (DOE 2013b), indicating a trend toward accelerating solar and gas as part of the country's energy diversification. South Africa's location on the continent with its diverse geography, coastline and climate offers the country abundant wind and solar resources. Furthermore, the wood and sugar plantations of the tropical eastern side of the country provides potential for biomass fuel, and although a semi-arid country, there is also some potential for small-scale hydropower (DOE 2015b).

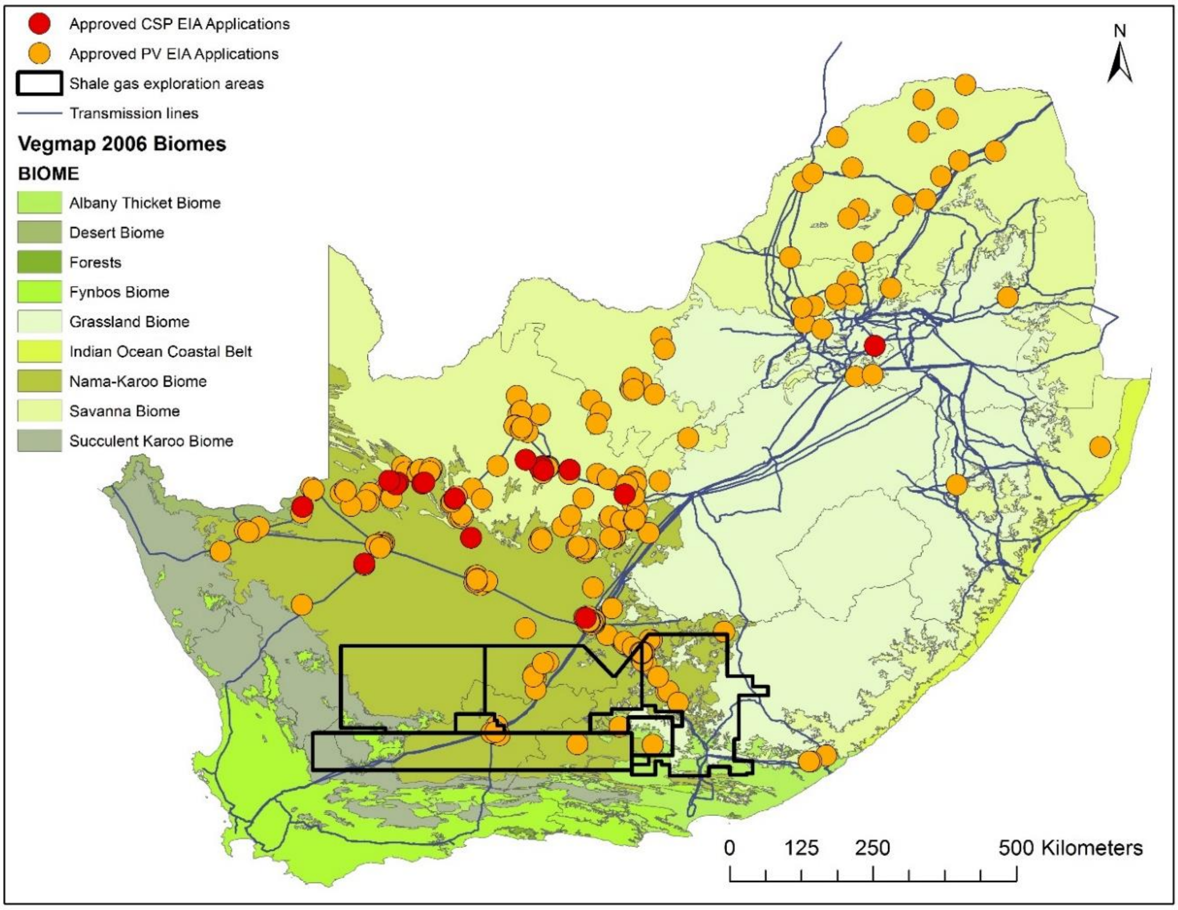


Figure 1.2 The biomes of South Africa, the distribution of approved environmental impact assessment applications for concentrating solar power (CSP) and photovoltaic (PV) power plants, and the areas for which shale gas exploration rights applications have been received (SANBI 2006; PASA 2015; DEA 2016).

In 2011, the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) was launched by the Department of Energy (DOE) as the implementation program for renewable energy capacity stipulated in the IRP. The REIPPPP is the first successful renewable energy program in South Africa (DOE 2015). It has been successful in contributing the most to the renewable energy generation capacity in South Africa as it is allocated in the IRP2010 and the draft IRP Update of 2013 (DOE 2011; DOE 2013b).

To date, the REIPPPP has awarded renewable energy projects throughout four rounds at competitive tariffs from 2011 to 2015. These projects include allocation to the two different solar energy technologies, concentrating solar power (CSP) and photovoltaic (PV) power, which were awarded in projects during the first four bidding rounds of the REIPPPP. The IRP Update allocated 3300 MW to CSP and 9770 MW to PV (DOE 2013), of which approximately 20% have been committed to projects in the first four rounds of the REIPPP for both CSP and PV. Descriptions of these technologies and the capacity allocations to other renewable energy technologies are included in Chapter 2.

Similar to the renewable energy capacity planned for in the IRP Update, shale gas is also being considered as a future contributor to the country's energy mix (NPC 2012). Shale gas development, however, has been limited to planning and research to date, with oil and gas companies in the process of obtaining exploration rights for demarcated areas in the Karoo (PASA 2013). The approximate size of South Africa's shale gas reserve is yet to be determined, but estimates range from 33 – 485 Trillion cubic feet (Tcf) (Boyer et al. 2011; Kuuskraa et al. 2011). These estimates are significant, considering that the Mosgas project near Mossel Bay on the south coast was initiated on a reserve of 1-3 Tcf (Mills et al. 2012; Vermeulen 2012).

Generally water-scarce and facing a severe drought at time of writing, planning and management related to development in South Africa is regularly confronted with competing needs within the food-water-energy nexus. The relationship between water and energy is intricate and can be viewed as direct, indirect or embedded, but ultimately water and energy issues cannot be viewed separately (Gulati et al. 2013). Similarly, the energy and environment interface is complex and dynamic (Dincer 1997), offering a challenging but interesting study area.

1.1.3. Impacts and impact assessment of energy development

Inherently, impacts of energy developments vary greatly and can be grouped and/or described in different ways. In a broader sense and in addition to environmental impacts, economic- and social impacts are relevant to sustainable development (World Energy Council 2015). The spectrum of impacts from energy developments can conveniently by categorised into four major groups by delineating independent impact characteristics, namely adverse versus beneficial, and direct versus indirect. Table 1.2 shows four different environmental impact categories with examples. The scope and objective of this thesis is limited to adverse direct environmental impact and should hereafter be interpreted as such.

Table 1.2 Four environmental impact categories with examples of each. Adverse direct impacts (shaded) are the focus of this study.

	Beneficial	**Adverse**
Direct	Making use of renewable energy resource	Vegetation clearing
Indirect	Carbon emission avoidance	Changes in nutrient cycles

Environmental Impact Assessments (EIAs) are governed by law under the National Environmental Management Act (Act no. 107 of 1998; RSA 2014) as an appropriate measure taken to regulate the effects from different categories of development activities at a project-level application. All committed CSP and PV projects have been subject to an EIA prior to commencement of construction. A Strategic Environmental Assessment for Shale Gas Development (SEASGD) was underway at the time of writing to broadly investigate the expected social, economic and environmental impacts of shale gas development in South Africa (CSIR 2015).

Being a project-level application, impact assessment tools are applied at local, power plant- or facility-scale, but biotic and abiotic factors within ecosystems vary across the landscape (Wiens 2002). Within this heterogeneity, gathering information on the impacts from several plants across the landscape is needed to draw up a more informative outlook on regional risks. A regional approach focused on environmental impacts offers valuable input to be integrated into regional and/or national policies and plans as well as the EIA process in the future.

As indicated earlier, the primary environmental impact associated with conventional energy technologies, which is predominantly fossil energy in South Africa, is that of CO_2 and other greenhouse gas emissions

(Dincer 2007). However, solar power and shale gas developments have further associated unique and context-specific impacts (e.g., Tsoutsos et al. 2005; Brittingham et al. 2014).

Some context was provided here regarding the status and plans of South Africa's energy system and its diversification, the distribution of solar and shale gas resources and the current method used for assessing possible environmental impacts. The scope of this study was focused around the major energy technologies to be developed in the arid regions of South Africa represented by the Nama-Karoo and Savanna biomes. This background suggests scope for improved understanding of impacts which guides the research scope and objective.

1.2. Problem statement

This work is motivated by the observation that energy developments and plans have recently significantly increased in the Nama-Karoo and Savanna biomes and are expected to continue to increase in number and potential impact. These impacts are currently only captured in the aforementioned EIAs. The spatial extent of impacts is potentially significant in the study area. In light of the diversification of South Africa's energy future, identification and understanding of the associated impacts on the natural resources of the area is considered important.

This work is relevant to conservation within the study area and to conservation planning as it provides a valuable opportunity to evaluate experiences and findings of initial impact assessments and studies, which in turn could inform mitigation and preventative measures. It also has the potential to better understand the interaction between different land and water uses, particularly in arid landscapes. With little to no experience of solar or shale gas at any significant scale (as at utility-scale) until recently, knowledge about these energy systems applied in South Africa is understandably limited; this is reflected in the lack of publications available. On a higher level, this topic of investigation is valuable in the framework of sustainable development in South Africa as it recognises renewable energy technologies as part of the country's future and commitments to carbon emission reductions.

1.3. Research objectives and questions

Following the background for this research and the problem statement, the overall objective is to identify and investigate the adverse direct impact of solar power and shale gas developments in the Nama-Karoo and Savanna biomes at a local (project) level based on initial experience. The aim is to put these findings in context at a regional scale to provide an outlook on the projected future.

The following questions were asked to reach the objective mentioned above:

1. With specific focus on the Nama-Karoo and Savanna biomes, what technology-specific 'facility' characteristics have the potential to directly and adversely impact the arid interior of South Africa?
2. What is the distribution and location of established and planned power plant/shale gas developments in the region?
3. Which bioregions/vegetation types/land use types would be impacted most significantly, and will different ecological proxies (e.g., fauna, soil) be impacted by the different components associated with these energy technologies?

4. What are the perceived differences in the adverse direct impacts of solar power on the natural environment throughout the different phases of development, *i.e.,* construction and operation for solar power and exploration vs. construction and production for shale gas?
5. Are there any apparent red flags and/or contingency risks with regards to water usage or impact on protected areas?
6. How would an increase in the above-mentioned impacts look if generation capacity allocation for solar power technologies (in MW) and shale gas resource potential and development (in Tcf) were increased?
7. What can be done to mitigate, minimise or manage impacts?

1.4. Research method

A mixed-method approach involving a combination of techniques such as interviews, site visits, Geographical Information Systems (GIS) analysis and literature reviews was used in this study and customised to either solar power- or shale gas development, depending on available data.

Guided by the objectives and limitations of this study and in order to answer the associated research questions, the approach that was followed can be summarised as follows:

- A literature review of energy and renewable energy in South Africa, impact assessment methods, relative policy and legislation, technology descriptions, land use and disturbances within the two biomes and the environmental impacts of utility-scale CSP, PV power and shale gas development;
- Identification of areas under solar power development and areas identified where shale gas development is likely to occur;
- Conducted interviews, site visits and GIS analysis, identifying technology-specific impacts locally (at project level) and across the study area/region and investigating the distribution of planned and current developments within biomes and/or vegetation types;
- A synthesis of impacts identified through the various data collection techniques to form a description of impacts from solar technologies on the arid biomes of South Africa and the prospective impacts of shale gas development in the Karoo environment;
- Recommendations for guiding management-, minimising- and mitigation measures to limit identified existing impacts as well as potential future impacts;
- A conclusion of key findings and recommendations for future studies.

1.5. Assumptions

Where needed, the underlying assumptions that guided the approach and methodology can be summarised as follows:

- Though it was not officially promulgated, the draft IRP Update of 2013 is used as the latest reference for electricity generation capacity expansion. The capacity allocated through the IRP Update will be built according to the timeline proposed in the IRP Update through the REIPPPP or a similar programme;

- The location of future CSP and PV power plants will generally be similar to that of projects currently in operation or construction;
- The distribution of biomes and vegetation types are as per the publically available vegetation map on the South African National Biodiversity Institute's BGIS website (http://bgis.sanbi.org/SpatialDataset);
- Exploration rights will be issued to exploration companies to establish the size of the gas reserves in the Karoo Basin and to determine economic feasibility of these reserves;
- Shale gas development in the Karoo Basin will continue if the size of the reserve deems economically feasible and will be limited to the identified exploration areas;
- The investigation of possible construction of additional energy infrastructure to convert gas to other energy carriers (e.g., gas-fired power plants) is not included here;
- The spatial footprint, water usage, chemical usage and construction timelines of energy developments were based on the best known regulations at the time of writing.

1.6. Definitions

Due to the interdisciplinary nature of this work, a comprehensive list of acronyms, abbreviations and key terms and concepts have been included in the front matter of this thesis. It should be noted that specific terminology in this study can have significantly different meanings between disciplines and that foundational knowledge or principles in a given discipline will not be common to others.

1.7. Delineations and limitations

In the EIA process, the concept of 'environment' is used as a unifying concept for the natural resources within a specific geographical area as well as social aspects and relationships, such as socio-economic status and/or health and safety of the community or focus group within that area. This understanding of the term 'environment' is then what is communicated to developers who have to comply with the regulations that have been set out (Republic of South Africa 2014)

The value of an energy technology within South Africa's society is important to job creation, skills development, impact on livelihoods and access to electricity, and it is a key field of study to understand the holistic influence thereof (Pollet et al. 2015; Baker et al. 2014). Acknowledging that the need for energy is central to human well-being and economic development, the work done for this thesis did not consider the entire spectrum of relationships between the natural environment and social and economic aspects. The impacts on natural resources within the studied geographical area were thus the primary focus.

In the words of Saldana (2015), "*Quantitative analysis calculates the mean. Qualitative analysis calculates meaning*." Social enquiry thus offers further value in assessing and investigating the dynamic relationship between solar developments, technology types, the associated environmental impact and the people who guide the various processes. Regarding the interviews included for this work, there are some inherent limitations due to the level of confidentiality a researcher and/or employer of a project developing company is at liberty to disclose. It should be recognised that individuals who participated in the interview process or surveys differ in terms of personality, culture and context, and consistency between them cannot by inferred. As the popular saying goes, "*talk is cheap*", and in this context it would be erroneous to interpret verbal contributions in isolation. Jerolmack and Khan (2014) describe this occurrence amongst social researchers as the '*attitudinal fallacy*'.

CSP, PV and shale gas exploitation are different in terms of potential, level of developmental experience and application (e.g., Hernandez et al. 2014; Weber & Clavin 2012; NPC 2012), and the impacts associated with these technologies are also expected to be different. These technologies are included in this study because the resources thereof overlap geographically, and each is included in South Africa's energy future (Figure 2). The objectives are thus limited to initial identification of impacts and mitigation measures, but inter-technology relationships and impact comparisons were not explored.

The relatively sudden emergence of solar power and shale gas activities is likely a significant reason for the lack of data and uncertainty regarding timelines associated with both technologies but especially with shale gas. This emergence could be considered 'disruptive' and suggests that all environmental impacts should be thoroughly investigated. All other things equal, the scope of this study was limited to focus on the natural environment. It was assumed that in combination with other studies investigating broader impacts (e.g., social impacts), the findings presented here would remain valid and contribute toward reaching this study's objective.

1.8. Significance and contribution

The *academic significance* of this work lies in the focus on environmental impact and the scope of the work. This topic of study began to take shape when no peer-reviewed academic literature could be found on the deployment of the relevant energy technologies within the study area. Additionally, no academic studies could be found that were conducted in South African environments and focused on the technology-specific characteristics with an outlook across technology types at a regional scale.

The *practical significance* lies in the research methodology to investigate the research problem and provide a description of impacts from solar power and shale gas developments. The work also is believed to be practically significant in terms of investigating how these developments will co-locate and have an impact on the relatively undeveloped arid regions in this study. Furthermore, there is opportunity to build on, adapt and improve the methodology and scope used in this work as energy development continues in South Africa alongside increased experience on this front.

1.9. Chapter overview

Chapter 1: Introduction

The background and context of the thesis are introduced. Here, the problem statement and research objectives are given followed by the research methodology, assumptions and contributions.

Chapter 2: Literature review

Past research on broader concepts that form the foundation of the research project and the thesis are presented. More specific literature and descriptions are included on themes such as sustainable development, the energy system of South Africa, technology-specifications, known environmental impacts associated with the technologies, the study area and impact assessment methods. The literature review aims to provide sufficient context to a reader without prior knowledge of South Africa's energy system, plans or the environmental impacts associated with solar power and shale gas developments.

Chapter 3: The impacts of solar power development

This chapter presents an initial investigation into the direct environmental impact of utility-scale CSP and PV power plants in the Nama-Karoo and Savanna biomes. An outline of the method is included in this chapter. Findings from structured interviews, site visits and spatial analysis are discussed together in relation to the landscape and the potential future outlook of these impacts.

Chapter 4: The impacts of shale gas production

An initial investigation is presented into the prospective direct environmental impact of shale gas production predominantly on the natural environment of the Nama-Karoo biome. The study area comprises the area where exploration right applications have been received for the Karoo Basin. An outline of the method is given again with specific reference to aspects that differed from the method in Chapter 3. Environmental impacts found from literature are supported by findings from structured interviews and the findings of a strategic environmental assessment for shale gas.

Chapter 5: Findings and recommendations for management and mitigation of impacts

This chapter presents findings from the interview process and observations from the site visits. The findings offer insight and recommendations for the management and mitigation of the impacts of solar power and shale gas developments in South Africa; they are supported by literature and legislative guidelines where applicable.

Chapter 6: Conclusion

The key findings from this thesis are consolidated and formed into a message that would be valuable to related or follow-up projects. Critique on the methods used, contributions made through the thesis and recommendations for future work are also outlined.

Appendices

These documents offer extended information on the method and findings to support the information and results presented as part of the main content.

CHAPTER 2: LITERATURE REVIEW

The aim of this chapter is to provide a comprehensive review of literature regarding renewable energy-and shale gas development as well as the environmental impact assessment thereof. This chapter starts with a concise description of sustainable development and the linkage with a transition towards a more diverse energy system. A description and outlook of South Africa's energy system is followed by a summary of legislation and policy documents relevant to energy planning and environmental management. Concentrating solar power (CSP), photovoltaic (PV) power and shale gas are then described together, with an overview of recorded environmental impacts associated with each. The study area and its current land uses are briefly introduced. The chapter concludes with a review of the most commonly used impact assessment approaches/methods.

2.1 The bigger picture: sustainability and sustainable development

Historically, environmental practices and energy planning represented two separated schools of thought and policy arenas. In present times, the implementation of activities in these two fields often overlap as they share a common goal, *i.e.,* to improve the sustainability of societies or entities while contributing to sustainable development (Popp et al. 2010). Considering energy systems and energy technology development alongside environmental systems has become increasingly important as the former is embedded within the latter.

Together with promoting energy saving and energy efficiency, the larger scale deployment of renewable energy is contributing to a global effort to lessen the ramifications of fossil energy, both from a climate change and sustainable development context (Winkler & Marquand 2009). Ultimately a movement towards renewable energy is considered more socially and ecologically sound, and in recent years it has proved to be even more economically attractive than some conventional energy technologies (Akella et al. 2009).

The term, 'sustainability', is used across various sectors. The understanding of this term has certainly come a long way since the Brundtland Commission's report in 1987, which aimed to advocate that economic growth can be based on policies that do not harm or destroy natural resources (Brundtland et al. 1987). Sustainability science not only presents opportunities for research in ecology but supports the legislative and administrative processes of development to focus on the interactions between the natural environment and society (Clark & Dickson 2003).

Since the early 1990's, there have been plans to base sustainable use and development on scientific information and known concerns related to natural resources and environmental impact. However, history has proven there is seldom scientific consensus when natural resources and the environment are the matters at hand (Stern et al. 1996; Leung & Yang 2012). Continuous resource exploitation is evidence of this, and such exploitation often does not come to a halt before resource collapse or extinction (e.g., Ludwig et al. 1993).

The global decline and extinction of species as a result of increased development-related pressure on natural resources, together with the contribution of atmospheric emissions to climate change (e.g., Rockström et al. 2009), has led to several actions taken to reduce damage while maintaining developmental goals. Such global attempts include the Millennium Development Goals (United Nations

2015) and commitments to the United Nations Framework Convention on Climate Change (United Nations 1992). Conversely, there is greater demand for the use of environmental assessment approaches such as an Environmental Impact Assessment (EIA), which is an example of a more practically implementable attempt to decrease the pressure developmental activities have on natural resources and the ecological health of the world's ecosystems (Dincer 1997; Treweek 1999).

Similar to other energy technologies, renewable energy technologies are dependent on natural resources as well as have an impact on them. Sustainable use principles such as the White Paper on the Conservation and Sustainable use of South Africa's Biological Diversity (Biodiversity Policy in short) (DEAT 1997) should thus be viewed in connection with such developments and/or developments within other sectors that occur in the country.

'Sustainable use' is one of the guiding principles of the Biodiversity Policy, explicitly stating that benefits derived from using biological resources in South Africa must be dependent upon the following (DEAT1997; pp 21):

i. the rate of resource use not exceeding capacity for renewal;
ii. resource production not affecting ecological integrity of the specific natural system;
iii. minimising or avoiding irreversible change by humans;
iv. ensured conservation and sustainable use of biodiversity by adequate investments; and
v. minimising or avoiding adverse impacts associated with using non-renewable biodiversity resources.

From this guiding principle in the Biodiversity Policy, there is evidence for an intention to ensure future availability of both renewable and non-renewable biodiversity resources. Further policy and legislation pertaining to the natural environment of South Africa (e.g., the National Environmental Management Act no. 107 of 1998) is discussed and mentioned in later sections.

2.2 The status of South Africa's energy system diversification

South Africa has one of the most energy-intensive economies, relying predominantly on a coal mining industry, which contributes to high carbon emissions (Pretorius et al. 2015; Winkler & Marquand 2009). In addition, the country is dependent on electricity supplied by a centralised, state-owned utility (Pollet et al. 2015). The aforementioned issues represent some of the concerns for the sustainability of the system, the associated socio-economic and environmental injustice as well as the pledge taken by the South African government to follow mitigation measures in order to meet targets set by the United Nations Framework Convention on Climate Change (RSA 2015).

Proven oil and gas reserves and production are limited in the country, leaving coal to account for approximately 72% of the total primary energy supply (U.S. EIA 2015). The current South African electricity generation system, consisting predominantly of an aging coal power fleet, has proven to have some challenges and at times struggled to continuously supply to the demand of the system (Scholvin 2014). This shortfall in supply capacity results in scheduled power outages, known as 'load shedding', which has further direct and indirect social and economic impacts (Pollet et al. 2015). The challenges described above form part of the context within which policies and plans are developed for diversification of the country's energy system.

There is a history of policy and legislation documents to guide energy sector planning in South Africa, but the implementation of these seemingly falls short due to the complexity of the context within which they are intended to be deployed (Sebitosi & Pillay 2008; Scholvin 2014).

A concise overview of the current and planned electricity generation diversification is provided below, followed by a summary of relevant policy and legislation related to the environmental and energy regulation and planning in section 2.3.

The first White Paper on Renewable Energy (hereafter, 'Renewable Energy White Paper') was released in 2003. Its proposal for renewable energy in the country has since progressed to the roll-out of numerous renewable energy projects. The Renewable Energy White Paper not only recognises the potential of renewable energy in the country but provides an outline of the vision, policy principles, goals and objectives of the government for including and promoting renewable energy at a national level. Most of the renewable energy projects were built through the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP), which started in 2011; some of these projects are still under construction. Table 2.1 summarises the total capacities allocated per technology throughout the programme to date.

Table 2.1 Total capacity allocated to different energy technologies in the IRP2010 and the draft IRP Update, where an increase in capacities to solar power and gas technologies can be seen. The total and remaining capacities to projects in Rounds 1-4 of the REIPPPP are given in the two right-hand columns (DOE, 2011, 2015a).

Technology	IRP2010 (MW)	IRP Update (MW)	Total allocated in REIPPPP (MW)	Allocation remaining in REIPPPP (MW)
Existing Coal	34746	36230	-	-
New Coal	6250	2450	-	-
Combined cycle gas turbines	2370	3550	-	-
Open cycle gas turbines	7330	7680	-	-
Hydro Imports	4109	3000	-	-
Hydro Domestic	700	690	-	-
Pumped storage	2912	2900	-	-
Nuclear	11400	6660	-	-
Wind	9200	4360	2660	660
PV	8400	9770	1899	626
CSP	1200	3300	600	0
Small Hydro	Not specified	Not specified	19	116
Biomass	Not specified	Not specified	16	19
Biogas	Not specified	Not specified	0	60
Landfill	Not specified	Not specified	18	7

Supply of natural gas is becoming increasingly important to global energy demands. Where the primary challenge of the past was to bring gas to the market, the exploration of unconventional gas resources such as shale gas, tight gas and coal bed methane now offers opportunities for more secure gas supply (IEA 2012; McGlade et al. 2013).

In terms of where gas fits into the South African energy diversification plan, reference is predominantly to the Integrated Resource Plan (IRP) for 2010-2030 (referred to as IRP2010) (DOE 2011), the draft update of the IRP (referred to as IRP Update) (DOE 2013b) and information provided by the National Planning Commission in the National Development Plan of 2012 (NPC 2012). Shale gas and liquefied natural gas imports from Mozambique and Namibia are the two major options to increase the volume of gas used in the energy supply (DOE 2013a). Although the size of the shale gas resource in the Karoo Basin has not yet been determined, current estimates vary quite significantly (US EIA 2015; Mills et al. 2012; Boyer et al. 2011). These estimates and other characteristics of the Karoo Basin are elaborated on in section 2.4.2. Despite the uncertainty related to the shale gas resource in South Africa, the IRP Update reflects increased allocation to open-cycle gas turbines and combined-cycle gas turbines (DOE 2013b), indicating a plan for an increase in the contribution of gas to the energy mix without certainty of future gas supplies.

Furthermore, determinations made by the Minister of the Department of Energy's (DOE) in 2012 (RSA 2012) require that South Africa's base load be supported by new generation capacity from coal, gas and hydro sources. The determinations made further specific requirements that gas-fired power generation contributes 3126 MW to mid-merit and/or baseload capacity. These requirements inspired the Gas-to-Power programme (DOE 2015b) which started with Requests for Information from participants and was followed by an appropriate procurement programme. Liquefied petroleum gas, liquefied natural gas, compressed natural gas, unconventional gas such as shale gas and coal bed methane are potential sources included in Requests for Information to the DOE (DOE 2015a), potentially establishing use and need for an indigenous gas resource.

The World Energy Council has developed a Trilemma Index (World Energy Council 2015) that gives a comparative ranking to benchmark the sustainability of the energy systems of 130 countries. The allocated score per country is an indication of how well the trade-offs between energy security, energy equity and environmental sustainability are balanced. In 2015, South Africa ranked 84th out of 130 countries in the overall index, showing a constant decrease in position for the past three years. The country holds 30th position for energy security, 87th position for energy equity and 130th position for the environmental sustainability of its energy system. As a consequence of these rankings and key characteristics of the energy system, in 2015 South Africa was added to the World Energy Council negative watch list. The purpose of the watch list is to identify countries in which significant changes have been experienced and/or can be experienced related to developments that the Index is constrained to capture and reflect. The primary reasons for South Africa making it onto the negative watch list are its capacity shortfalls, the need for load shedding implementation and the effect that has on the economy (World Energy Council 2015). Indices and rankings like these help put the condition of the country's energy status in global perspective, but it also indicate areas where efforts towards improvement should be focused.

2.3 Policy and legislation for energy and the environment

Understanding and knowledge of the relevant legislative and policy documents is key both to the context within which work is being done and to obtaining a holistic view of a system (Falkner 2014). Legislation in South Africa covers all aspects of society in the highest form within the Constitution (RSA 1996), and subject-matters are addressed in greater detail within specific legislation. South Africa's socio-economic imbalances stemming from a turbulent past have had an impact on current planning and implementation, so comprehension of governance and the constitutional framework is vital (Klug 2010).

The following sections highlight the current most relevant legislative and policy documents related to energy and the natural environment in South Africa.

2.3.1 Environmental

The highest legislative guidance to environmental practice in the country is stated in Section 24 of the Constitution of South Africa (Act no. 108 of 1996) (RSA 1996):

Everyone has the right -

- *(i) to an environment that is not harmful to their health or well-being; and*
- *(ii) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that -*
- *(iii) prevent pollution and ecological degradation;*
- *(iv) promote conservation; and*
- *(v) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.*

The National Environmental Management Act (NEMA in short, Act no. 107 of 1998), as the overarching governing law, has established principles to guide decision-making on matters concerning the environment through co-operative governance (RSA 1998). Chapter 5 of NEMA, 'Integrated Environmental Management', aims to ensure that appropriate environmental management tools are applied to enable integrated environmental management of activities. These tools are expected to have a potential impact on a) the environment, b) socio-economic conditions and c) the cultural heritage. The EIA Regulations (No. R. 982, 2014) mentioned in this chapter of NEMA regulate the procedures from preparation to decision-making for environmental authorisations of activities needing to undertake EIAs. In short, the purpose of the EIA Regulations is "*to avoid or mitigate detrimental impacts on the environment, and to optimise positive environmental impacts*". Following the EIA report which is relevant during the planning phase of a project, current solar power projects are managed by means of environmental management programmes during construction and thereafter through an environmental management system (RSA 2014).

Considering the wide coverage in South African environmental legislation, potential issues and governance related to the subject matter should theoretically not be of concern. However, as Rossouw and Wiseman (2004) argue, responsibilities within government might be ill understood due to the lack of a national strategic sustainable development framework. Additionally, environmental assessment tools are at risk of being discounted as a result of social, economic and environmental integration issues.

2.3.2 Energy

South Africa's energy legislation also has its roots in the Constitution of the Republic of South Africa (No. 108 of 1996). The Constitution requires the government to develop a national energy policy. The role of such a policy is described as ensuring that the energy needs of the nation are supplied by adequate use and distribution of the country's energy resources. Furthermore, this network of energy production and distribution must be conducted in a sustainable manner in order to improve the living standards of its citizens (RSA 1996). Preceding the building of new energy infrastructure (e.g., electricity generation capacity and liquid fuel refineries), legislative documents are followed-up with national plans. Table 2.2 summarises the relevant legislative documents and plans that have contributed to the current national planning environment.

Table 2.2 A chronological summary of the primary relevant legislation and policy documents regarding the country's energy system.

Year	Legislative document/Plan	Relevance and role in energy planning and implementation
1998	White Paper on Energy Policy (DME 1998)*	Proposal towards fulfilling the requirement of a national energy policy as stated in The Constitution.
2003	White Paper on Renewable Energy (DME 2003)**	The formal incorporation of renewable energy sources into the energy mix of South Africa and the renewable energy policy environment.
2008	National Energy Act (RSA 2008)*	The overarching law governing the energy system of South Africa.
2010	Integrated Resource Plan for Electricity 2010-2030 (IRP) (DOE 2011)**	The master plan for new electricity generation infrastructure in South Africa.
2012	National Development Plan (NDP) (NPC 2012)**	Outlines the 2030 vision for South Africa's energy sector.
2012	Draft Integrated Energy Plan (IEP) (DOE 2013)**	Aims to represent a balanced view of the objective of the various other high impact policies, the Energy White Paper and National Energy Act.
2013	Draft IRP Update (DOE 2013b)**	Draft IRP Update, not yet promulgated. Same role as the IRP2010.

*Direct or indirect relevance to Renewable Energy planning

**Direct or indirect relevance to both Renewable Energy and Natural Gas planning

As previously mentioned, the Renewable Energy White Paper represents the first formal incorporation of renewable energy resources into the energy diversification plan and policy environment of South Africa (DME 2003). The IEP was developed as a requirement of the National Energy Act (Act no. 34 of 2008) to address national energy supply, demand balances and make proposals on capacity expansion based on various constraints and assumptions. Specific infrastructure planning such as those involving electricity, liquid fuel and gas are dealt with in topic-specific plans and roadmaps with the intent that they feed back into the integrated energy planning process (DOE 2013a).

The history of legislative and policy development for shale gas is shorter than that of renewable energy resources. The Department of Mineral Resources placed a moratorium on hydraulic fracturing for shale gas in South Africa (DOE 2013a), but this was lifted in September 2012, making South Africa the first country to reverse the decision to ban what is regarded by some (Warren 2013) as a controversial technique for obtaining energy. Apart from the direct or indirect inclusion of natural gas in the country's mix of energy resources as indicated in Table 2.2, updated regulations were published under the Mineral and Petroleum Resources Development Act (Act no. 28 of 2002) for petroleum exploration and production; these include practices specifically relevant to shale gas (DMR 2015). Furthermore, the DOE is in the process of finalizing a Gas Utilisation Master Plan for South Africa; this is expected to be a 30-year plan for developing an indigenous gas economy based on resource potential and analysis of existing market and context related parameters (Fichardt 2014).

The record of South Africa's energy policy and legislative developments should be viewed with appreciation of the fact that energy policy development is a timeous process facing challenges such as political agendas, infrastructure planning and competing energy visions. These are all factors playing key roles when policy developments are regarded as enablers of country-wide energy transitions (Baker et al. 2014).

2.4 Energy technologies and impacts overview

The life cycle impacts of large-scale solar power developments can be either beneficial or detrimental and are grouped into the following categories by Turney & Fthenakis (2011): issues related to land use, human health and well-being, wildlife and habitat, geohydrological resources, and impacts on climate and greenhouse gases. These categories, albeit broad, are seemingly sufficient to capture detailed impacts related to solar, shale gas technologies and, if required, conventional energy sources (Panwar et al. 2011; Dincer 1997; Brittingham et al. 2014).

Large scale solar energy is represented by two technology categories, CSP and PV. The size and location of solar power plants are determined by the intended use of the electricity produced at the plant and the availability of relevant solar resources. These power plants can then either be utility-scale or embedded within areas of need. The latter refers to smaller systems (e.g., < 1 MW) and is known as distributed generation capacity, which functions independently from the grid (Boyle 2012a). Unless otherwise stated, further description refers to utility-scale power plants for both CSP and PV.

Different to traditional extraction of natural gas from shallow gas wells by drilling, the extraction of shale gas has become economically viable through the advances made in horizontal drilling techniques and hydraulic fracturing (Kinnaman 2011). However, the economic gain from this energy resource and the associated environmental impacts are widely disputed (e.g., Kerr 2010; Hedden et al. 2013; Milt et al. 2016). For the purpose of this study, shale gas extraction refers to the process which includes horizontal drilling followed by hydraulic fracturing.

Literature provides a record of assessments of the impacts from both solar power and shale gas technologies from various perspectives, including customised definitions according to objective-specific questions (Dincer 1997; Fthenakis & Kim 2009; Branosky et al. 2012). Previous studies have considered a broader scope by including impacts typically of life cycle analyses (e.g., Ehtiwesh et al. 2016; Corona & San Miguel 2015; Branosky et al. 2012) such as energy balances and socio-economic impacts. Recognizing the value of such comprehensive assessment, the focus throughout this study was on adverse direct environmental impacts during the construction- and operational phases of solar power plants and during the exploration to production of shale gas development. In this section a brief description of CSP, PV and shale gas technologies is provided, followed by an overview of the direct environmental impacts associated with each.

The footprints of energy developments, such as the area occupied by a power plant or a well pad, represent a physical component in the energy production process. These need to be supported, however, by infrastructure that facilitates transport or evacuation of the energy and/or materials needed for operation from the place of production to the place of need, *i.e.,* access roads and power lines or pipelines (Lathan & Boutin 2015). These are described as 'linear activities' in environmental assessment regulations, but they are not assessed to the extent of the main development for which such assessment is being done, referred to as an 'activity' or 'activities' (RSA 2014). When investigating the environmental impact of energy development across a landscape as this thesis aimed to do, corridors such as roads, transmission lines and pipelines need to be recognised for their contribution to habitat fragmentation, possible contribution to direct mortality and hindrance to animal movement (Andrews 1990; Milt et al. 2016). The impact of power lines on birdlife has particular coverage in the literature. Here, the source of mortality is predominantly electrocution or collision, depending on the resource use and wing morphology of species at a specific location (e.g., Bevanger 1998; Janss 2000; Chevallier et al. 2015).

2.4.1 Concentrating solar power

Concentrating and converting sunlight into useful mechanical work dates back to the 19th century with more developments and improvements made to the technology closer to the 20th century. In terms of globally installed generation capacity, CSP is still behind other renewable energy technologies such as PV, wind and hydro power and does not feature exclusively in some global energy outlook reports (e.g., U.S. EIA 2016). Approximately 6000 MW CSP capacity is currently installed globally. However, based on current policy, Teske et al. (2016) predict an estimated 4.4- and 14-fold increase in this capacity by 2030 and 2050 respectively. This international upward trend for CSP is reflected at a smaller scale in the capacities included in South Africa's IRP2010 and IRP Update, summarised in Table 2.1.

Today there are four main CSP technology types: parabolic troughs, central receivers (aka power towers), linear Fresnel and parabolic dish concentrator systems (aka dish Stirling) (Everett 2012). Parabolic troughs and central receivers are currently the dominant representatives of CSP as well as the only two CSP technology types being deployed through the REIPPPP in South Africa. Consequently, only these two CSP technology types are included in this study.

The solar field or collector area and an area collectively referred to as the 'power block' with the balance-of-plant infrastructure are the two most prominent components occupying land area of both central receiver and parabolic trough plants (Lovegrove & Stein 2012). The solar field in parabolic trough plants and central receiver plants (see Figure 2.2 and Figure 2.3) are always different, and the configuration of the power block depends on the specifications of each particular power plant irrespective of the CSP technology type (e.g., Lovegrove & Pye 2012).

Apart from usual impacts associated with industrial construction activities, such as dust increase, noise impact, increased traffic and virtual intrusion (Tsoutsos et al. 2005), other overlapping direct environmental impacts of parabolic troughs and central receiver plants include those involving land use, biodiversity, visual changes or hindrances, and water resources (Turney & Fthenakis 2011). These impacts are discussed below.

The footprint of a CSP plant includes the directly transformed or impacted area from construction to decommissioning of such facility. Furthermore, the technologies' land use efficiencies are often compared in terms of land use requirements (Hernandez et al. 2014); these are calculated using various metrics and methodologies in the literature. Here, there is agreement with Horner and Clark (2013) who regard area unit per energy unit per year (e.g., ha/GWh per year) as an appropriate method for calculating land use requirements as it is based on actual electricity output and scaled to the life cycle of the power plant. The recorded total land use requirements of parabolic trough and central receiver plants differ slightly in the literature. However, after an assessment of a number of these plants in the United States (U.S.) it was found that the average total land use of parabolic trough and central receiver plants is 1.58 ha/GWh per year and 1.29 ha/GWh per year respectively (Ong et al. 2013).

Biodiversity is indirectly influenced through habitat transformation by all CSP developments, but the appropriate siting and management of construction activities offers an early and preventative measure for avoiding as many of these impacts as possible (Tsoutsos et al. 2005; IEA 1998).

Access roads associated with power plant development contribute to the transformed area and direct animal- and plant mortality (Carr et al. 2002), and fences hinder the movement of animals. These are two common impacts irrespective of the technology types, and the management and operational approaches to these impacts vary widely. Regardless of the presence of a development fence, aspects such as food availability, predator avoidance and feeding strategies will be altered within the development footprint (Turney & Fthenakis 2011), affecting the ecology of the system within which the development is located. In addition to the impacts associated with dust, roads and habitat destruction on wildlife during power plant construction in the Mojave and Sonoran Deserts of Southwestern U.S., Lovich and Ennen (2011) list potential impacts associated with the existence and operation of power plants. These potential impacts include habitat fragmentation, barriers to gene flow, noise effects, electromagnetic field effects, pollution from spills, risk of fire, light pollution and the indirect effect of water consumption. Even though the aforementioned authors could not collect any published literature on direct wildlife mortality, they specifically mention concern for subterranean animals at risk during construction activities, which compacts and/or disturbs soil structure. Biodiversity impacts specifically related to central receiver or parabolic trough plants are discussed separately.

As most CSP plants make use of a steam cycle and use additional water for mirror washing, water use and/or the impact of consuming water resources is considered to be potentially significant in arid environments (Tsoutsos et al. 2005) and is included in a number of reviews (e.g., Macknick et al. 2012; Hernandez et al. 2014). Ravi et al. (2014) analysed the water consumption of 10 CSP plants during construction and operation in the U.S. and found that about 48% of water is used for dust suppression and mirror washing, about 37% is used as process water in the steam cycle and about 15% is used during construction.

Macknick et al. (2012) reviewed water consumption data from published primary data and found the median water consumption for dry-cooled central receiver and parabolic trough plants to be approximately 98 L/MWh and 295 L/MWh respectively, and the median consumption of wet-cooled central receiver and parabolic trough plants is 2975 L/MWh and 3430 L/MWh respectively. These numbers are similar to the findings of Klein and Rubin (2013) who found the combined average water consumption for dry-cooled central receiver and parabolic trough plants to be around 300 L/MWh. All new power stations in South Africa are required to be dry-cooled, which offers a significant reduction in water consumption in the energy sector. This is also beneficial in light of the low rainfall in the areas of CSP deployment (Mucina & Rutherford 2006). Depending on the location of power plants, the transition from wet-cooled to dry-cooled systems has the potential for a 92% – 93% reduction in CSP water usage (Bracken et al. 2015). Accidental water pollution is considered a risk by Tsoutsos et al. (2005), but it seems to be a less-covered subject in the literature compared to water consumption. One possible reason for lack of research in this area may be the fact that solar power plants are often situated in desert environments (Lovich & Ennen 2011a). The plants in South Africa are required, and thus designed, to be closed loop, zero-effluent water systems. The waste water from the power cycle is deposited in evaporation ponds of which the brine gets disposed of at waste-treatment plants. To date, due to the relative limited operational timeframes of CSP plants in the Northern Cape, there has not yet been a need for brine disposal at waste-treatment plants in South Africa (HP van Heerden 2016, personal communication, 6 June).

As a result of operational and infrastructural differences between central receivers and parabolic trough plants, these two technologies also have mutually exclusive impacts associated with each (Tsoutsos et al. 2005); these are discussed in the next sub-sections.

Central receiver technology

Central receiver plants make use of many separate tracking mirrors called ‘heliostats’ to focus sunlight onto a receiver normally situated at the top of a tower (see Figure 2.1).

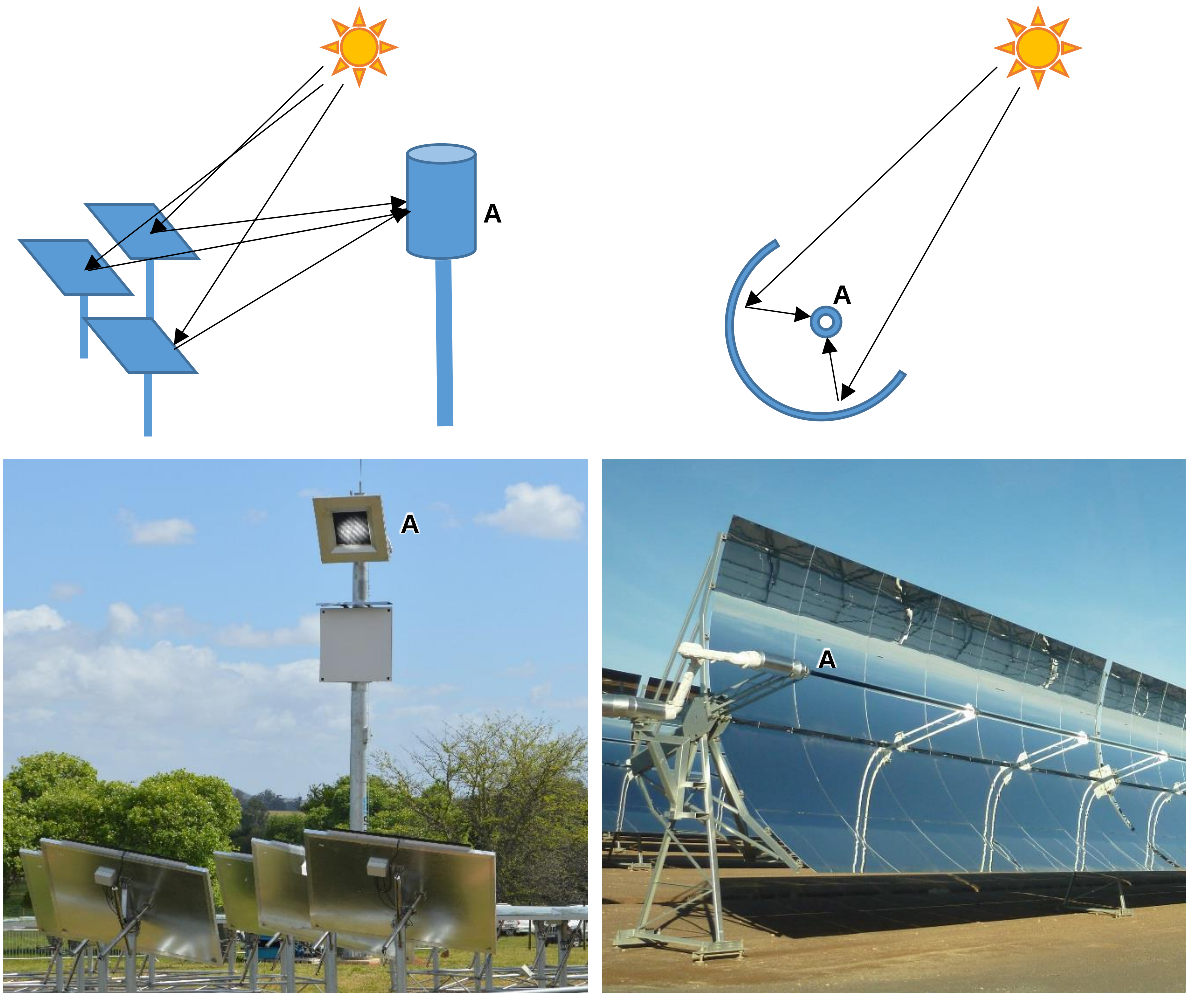


Figure 2.1 A simple schematic demonstrating the path of solar energy to the heliostats in a central receiver plant (left) with the Helio100 pilot plant (Stellenbosch University 2016) as an example and a parabolic trough (right) with the Kaxu Solar One plant (Abengoa 2016) as an example. In both schematics and photographs, ‘A’ indicates where the energy gets transferred to a heat transfer fluid. Photo credits: Justine Rudman.

The current most common commercial approach to TES is the use of two tanks containing molten salt. One is the hot tank (typically at 565°C) acting as the 'battery' when thermal energy is needed (e.g., at night). The other tank is a colder tank (typically at 290°C) in which the molten salt is reheated when sunlight is available again (Lovegrove & Pye 2012). Figure 2.2 is a satellite image from Google Earth of a direct steam central receiver with an indication of the various components of a central receiver development.

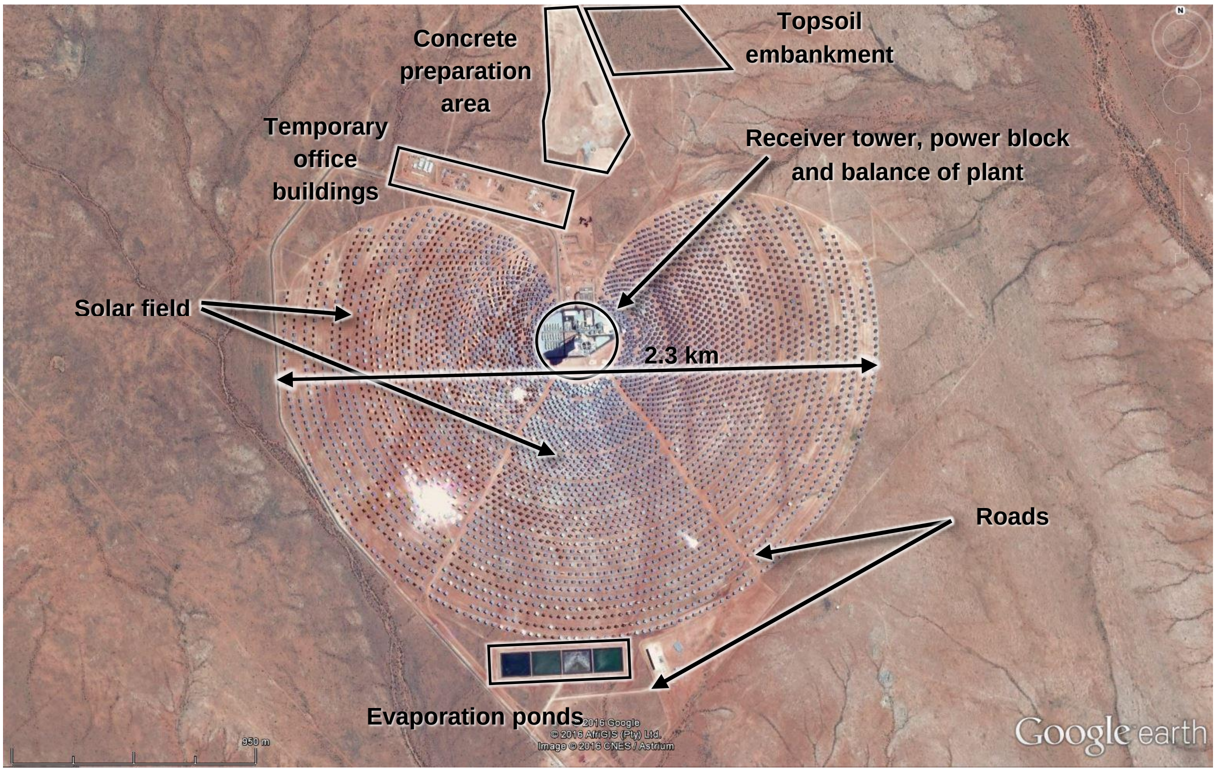


Figure 2.2 A satellite image of Khi Solar One, a 50 MW central receiver power plant outside Upington in the Northern Cape. In addition to the heliostat field and central power block, the different areas within the development footprint are indicated on the image. Photo credit: Google Earth.

Central receiver technology is less mature than that of parabolic troughs, which arguably poses a challenge for the analyses of environmental impacts of central receivers. A primary concerning biodiversity impact associated with central receiver plants is the risk imposed by areas of high solar flux around the receiver to avifauna. This impact has received negative attention in the media (e.g., Clarke 2013; Clarke 2015; Peck 2014), but there is also some evidence that this initial publicity is now being corrected with more reliable evidence based media reports (Fairley 2015). The work of McCrary et al. (1986) represents the earliest and one of few peer-reviewed records of avifauna mortality at the Solar One central receiver power plant in the Mojave desert. The solar power plant study area was considered to have an exceptionally high level of bird activity in comparison with other areas in the Mojave Desert due to agricultural lands and ponds in the vicinity. Thirteen flux-related bird mortalities of seven species were recorded over 40 weeks along with a high number of insect incinerations of undetermined species but the majority of which were aerial insects. Additionally, 57 collision-related bird mortalities of 20 species were recorded for a total of 70 mortalities subscribed to the presence of the solar facility at the end of the study period. Compared to the mean relative avian abundance recorded at this facility, the mortality numbers suggest that 0.6% – 0.7% of the local bird population was affected during this time, which is expected to be lower when the annual regional population is taken into account.

Kagan et al. (2014) studied bird carcasses from one central receiver plant in southern California and found most fatalities were due to solar flux incidents. Although no evidence was found of significant solar flux-caused tissue- or eye damage, singed flight feathers causing impaired flying and less effective predation and predator evasion is determined to eventually lead to starvation or predation of these birds. Kagan et al. also note the term 'mega-trap' as related to the term 'ecological trap', first described by Dwernychuk and Boag (1972). Here, 'mega-trap' is used to describe the way areas of high solar flux and intense light attract flying insects, of which many carcasses were observed throughout the study site. These insects attract insectivorous birds and the associated predators of birds. In this way, all are exposed to- and risk impact from multiple trophic levels. It should be noted that the carcass sampling methods in this study were opportunistic and not according to a predetermined method. Table 2.3 summarises the post mortem results from a central receiver and parabolic trough plant.

Table 2.3 Avian fatality causes and numbers at two CSP plants and one PV plant in southern California (Kagan et al. 2014).

Cause of death	Ivanpah Central Receiver plant (CSP)	Genesis Parabolic trough plant (CSP)	Desert Sunlight PV plant
Solar flux	47	0	0
Impact trauma	24	6	19
Predation trauma	5	2	15
Trauma of undetermined cause	14	0	0
Electrocution	1	0	0
Emaciation	1	0	0
Undetermined (carcass in poor condition)	46	17	22
No evident cause of death	3	6	5
Total	**141**	**31**	**61**

Ho (2016) summarised avian mortality per energy unit at CSP plants and found that the 0.7 – 3.5 fatalities per GWh was higher than that of wind and nuclear energy, but lower than fossil fuels. Furthermore, a range of deterrents are mentioned that still need to be evaluated for effectiveness. Considering that most bird fatalities at central receiver plants result from flying through high solar flux in focal or 'stand-by' points (as can be seen in Table 2.3), one would expect that reducing the flux in such areas (typically at approximately 600 kW/m^2 around the receiver) would reduce flux-related mortalities. Two U.S. central receiver plants have implemented a heliostat aiming strategy to reduce energy in focal- or 'stand-by' points to below 4 kW/m^2. This strategy has been successful at reducing the number of flux-related incidents at one of these plants (Kraemer 2015). Considering the emerging nature of this technology's deployment, its impacts and relative success with one mitigation strategy, this provides a perspective on how technological adaptations can be made where necessary.

Parabolic trough technology

Parabolic trough plants have solar fields which consist of long rows of concave mirrors that reflect sunlight onto an insulated receiver tube through which HTF is pumped. This HTF is usually synthetic thermal oil (see Figure 2.1) used to heat water that either produces steam for a steam turbine or goes to storage as described for central receiver plants (Lovegrove & Stein 2012). Figure 2.3 is a satellite image from Google Earth of two parabolic trough plants near Pofadder in the Northern Cape. A feature which can't be seen in the satellite image is that Kaxu Solar One and Xina Solar One are built on terraced areas as the different areas of the solar field need to be completely level.

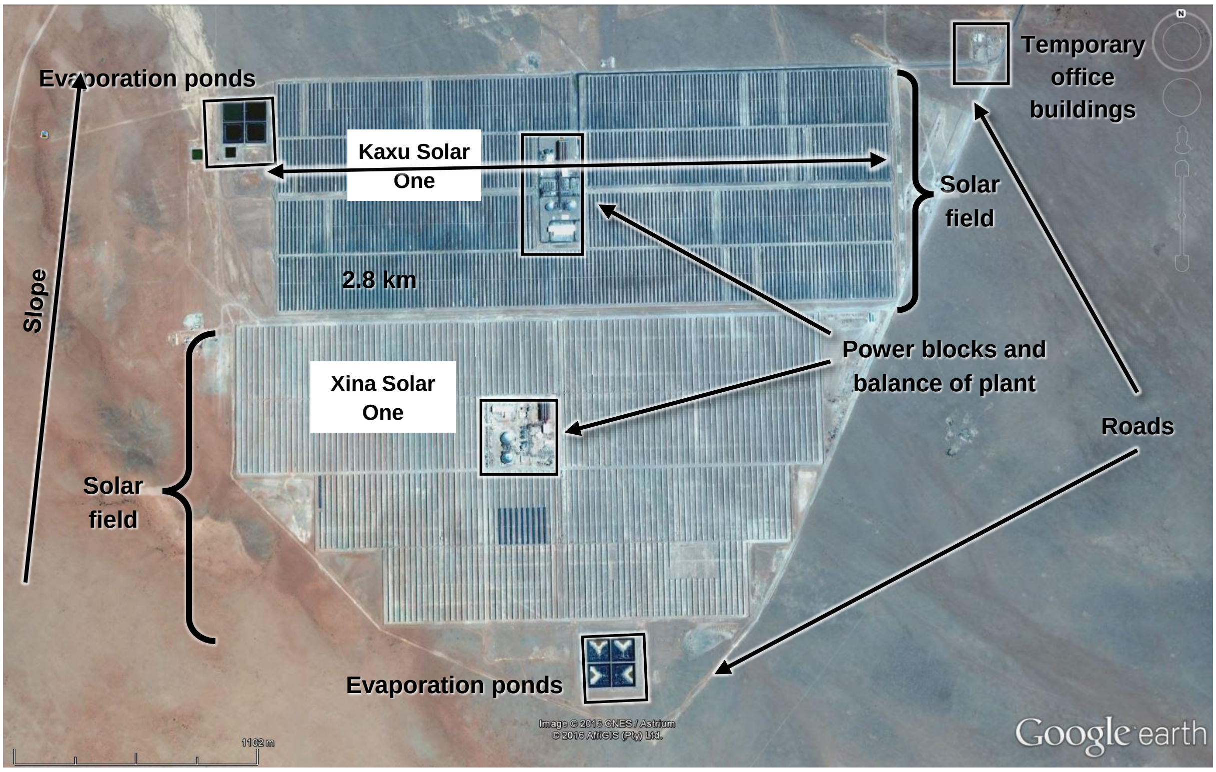


Figure 2.3 A satellite image of the 100 MW Kaxu Solar One and 100 MW Xina Solar One parabolic trough plants near Pofadder in the Northern Cape. In addition to the solar fields and central power blocks, the different areas within the development footprints are indicated on the image. Photo credit: Google Earth.

In addition to potentially significant water use discussed earlier, the accidental release of synthetic oil or water containing additives from the power cycle are the only other specifically mentioned impacts related to parabolic trough plants by Tsoutsos et al. (2005). Furthermore, Burkhardt et al. (2011) perform a Life cycle Assessment (LCA) of parabolic trough plants to investigate how design alternatives can result in lower life cycle greenhouse gas (GHG) emissions, less water usage and cumulative energy demand.

Early discoveries related to the 'photovoltaic effect' date back to the early 1800's, but first practical demonstrations of the use of PV cells happened in the mid 1900's when a U.S. space satellite was powered using solar cells. Following progress towards higher efficiency and cost reduction technology, large-scale PV power plants are now grid connected internationally (Boyle 2012b). After wind and hydropower, PV is widely deployed and contributes the third most electricity generated from renewable energy resources globally (U.S EIA 2016). According to the Technology Roadmap for solar PV by the International Energy Agency, the total global installed PV capacity of about 135 GW can increase approximately 13- and 35-

fold by 2030 and 2050 respectively (International Energy Agency 2014). The capacity included in the IRP2010 and IRP Update (shown in Table 2.1) for PV in South Africa is also a smaller-scale representation of this international upward trend for the deployment of this technology.

Simply put, PV cells transform solar radiation into electricity when the energy of photons displaces electrons in the semi-conductor material of a PV cell, creating an electric current. Together with voltage provided by the semi-conductor structure of individual cells, direct current power is produced by PV modules (multiple cells) arranged in arrays (multiple modules). This power is transformed to alternating current by inverters and then fed into the grid (Boyle 2012b; Fahrenbruch & Bube 1983). Several PV technologies are currently available and others are in development, but cry cells (e.g., polycrystalline- and monocrystalline silicon) are currently the most affordable and common. Other relatively common technologies include III-V cells and thin film technology, which are all different with respect to type or compound, purity of semi-conductor material and cell thickness (Miles et al. 2005). Concentrating PV systems are as commercialised as aforementioned technologies, but here a secondary reflective surface or lens is used to concentrate more sunlight onto a PV cell (Boyle 2012b). Within solar power developments and in combination with considering alternative cell technologies, arrays can also be fixed at an optimal tilt, tracking on a single-axis (*i.e.,* East-West) or tracking on a dual-axis (*i.e.,* North-South and East-West), depending on the preference and project design (e.g., Abdallah 2004). However, the different configurations of PV technology and choice of tracking-system do not make a major difference to the visual amenity of such power plants on the landscape.

PV power plant designs are unique, and depend on the type of technology used, the size of the development and the available resources. Figure 2.4 is a satellite image from Google Earth of a PV development near De Aar in the Northern Cape. Usually some administrative or operational support is needed at a PV power plant as additional facilities are required on site such as offices (temporary or permanent) and construction camps. However, the main functional components of a PV power plant remain the same and can be summarised as follows:

- The solar field, including the PV modules, also referred to as ‘panels’ which are connected to support structures and/or tracking systems; inverters and transformers to step-up the voltage of AC power from the inverters to the requirements of the grid;
- A grid connection interface, usually a substation where the power plant’s electricity is exported into distribution or transmission grid (Miller & Lumby 2012).

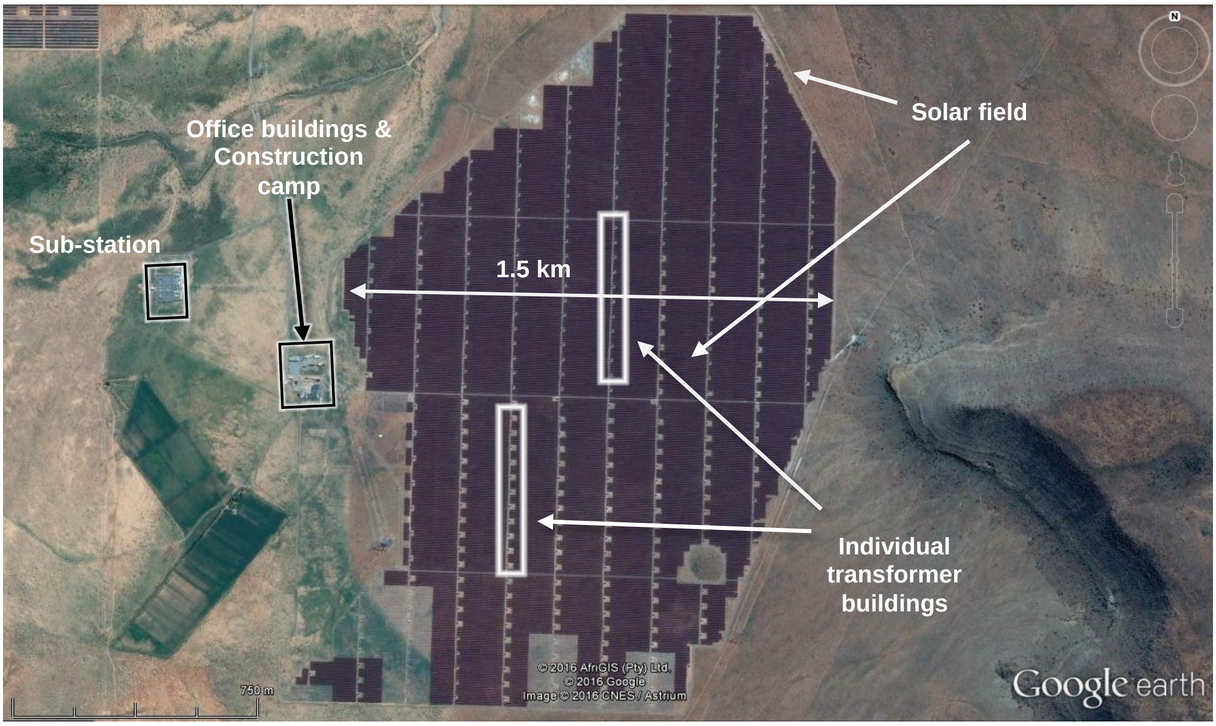


Figure 2.4 A satellite image of the 75 MW Solar Capital 3 fixed tilt thin film PV plant near De Aar in the Northern Cape. In addition to the solar field, the different areas within the development footprint are indicated on the image. Photo credit: Google Earth.

The environmental impact of PV power components has largely been documented as LCAs on the various module types (Bergesen et al. 2014). Here, the focus is regularly on greenhouse gas contribution, energy payback time, human health impacts and impacts on mineral resources (e.g., Wild-scholten 2013; Desideri et al. 2013; Hosenuzzaman et al. 2015). Some regard the direct environmental impact of PV power plants as 'benign' once in operation. However, noise and dust during construction, land use and visual impact during the lifetime of the plant and the risk of accidental leakage of hazardous material are all associated with the construction and operation of these plants (Tsoutsos et al. 2005).

Similar to CSP, the footprint of PV plants includes the directly transformed or impacted area during the construction and operation of the facility (Lovich & Ennen 2011b). Horner and Clark (2013) find significant variability in the methods used and results of studies on land use efficiency (also referred to as 'land use energy intensity'). After a study that included a total of 32 large PV facilities in the U.S. (*i.e.,* > 20 MW), Ong et al. (2013) find a range of land use requirements from 1.01 to 2.39 ha/GWh per year for a combination of fixed-tilt, single-axis and dual-axis tracking CPV systems. The average total land use requirement is 1.5 ha/GWh per year for large scale fixed tilt facilities and 1.34 ha/GWh per year for large scale single axis plants. Only smaller scale dual-axis PV facilities (*i.e.,* <20 MW) are included in this study with the average total land use at 2.23 ha/GWh per year. In a comparative study between renewable energy technologies and conventional energy technologies (e.g., coal and nuclear), Fthenakis and Kim (2009) claim that PV technologies have the lowest level of associated land transformation throughout their life cycles.

As a non-thermal renewable energy technology, PV power plants mostly require water for panel washing, which consumes relatively minimal amounts of water per energy unit (Macknick et al. 2012). Ravi et al. (2014) find that 40% of on-site water usage for PV is used for construction and 60% for panel washing.

Macknick et al. (2011) perform a comparative review of the operational water consumption of different electricity generating technologies and find the median consumption for PV power plants to be 98.42 L/MWh.

The footprint of PV power plants has an impact on biodiversity due to habitat transformation, which depends on the land where developments are located. Furthermore and similar to CSP, the presence of a development fence, roads and the effects of shading caused by PV panels are expected to have an effect on the vegetation and animal dynamics of the area (Turney & Fthenakis 2011). It is also possible that some species are attracted to some of the infrastructure components of these developments (Hernandez et al. 2014).

Kagan et al. (2014) argue that large areas of reflective panels might be mistaken for bodies of water by birds in a desert environment and find that 44% of the species recorded at the Desert Sunlight facility were water birds. The number and cause of fatalities at this facility is summarised with that of the two CSP technologies in Table 2.3.

In a Master's study conducted at a 96 MW PV plant near Postmasburg in the Northern Cape, Visser (2016) investigated the changes in bird communities within and near the development footprint along with their collision impact with facility infrastructure and conducts a comparison with other energy technologies (e.g., wind). The combined data collection for this study took place over the duration of three months. During this time, 53 different bird species and 12 fatalities were recorded at the study site. Most of the fatalities occurred in the solar field, and although feather spots found on solar panels indicated possible collisions, it was impossible to determine with certainty the cause of death. The remainder of the fatalities are believed to have resulted from vehicle and fence impacts. This study concludes that, despite limitations, fatalities recorded during this limited study period suggest an extrapolated estimate of 4.53 fatalities/MW per year; however, there is no clear evidence for a significant link between collision with plant infrastructure and mortality on site.

2.4.2 Shale gas

Shale, mainly consisting of hardened clay with a very fine-grained and an organic matter fragment, is Earth's most abundant sedimentary rock formation. Shale formations have traditionally been viewed as a source of hydrocarbons, but some organic rich shale deposits are now regarded as targeted reservoirs. Organic rich black shale is the most conducive to the formation of shale gas. Here, natural gas containing about 90% methane may have formed during any stage of the evolution of organic matter and remain trapped within nano-scaled pores within the impermeable rock (Zou 2013).

These organic rich shale deposits are referred to as unconventional reservoirs and resource plays. The permeability of oil or gas reserve formations are measured in darcy, based on Darcy's Law which is a function of reservoir pressure, flow pressure, formation volume, oil or gas viscosity and drainage area, amongst others things (Perry & Lee 2007). In contrast to conventional reservoirs where the rock permeability is greater than 0.1 millidarcy, reservoirs with less permeability than this are considered unconventional. These reservoirs can display a wide variety of physical characteristics in terms of depth, pressure, temperature, shape and homogeneity. Due to such diversity, definitions of these reservoirs also vary, but one such definition of unconventional gas reservoirs is the following:

> *Natural gas that cannot be produced at economic flow rates nor in economic volumes of natural gas unless the well is stimulated by a large hydraulic fracture treatment, a horizontal wellbore, or by using multilateral wellbores or some other technique to expose more of the reservoir to the wellbore* (Chinanelli et al. 2012).

Tight gas and coalbed methane resource plays are both considered unconventional reservoirs (Perry & Lee 2007; Chinanelli et al. 2012). A resource play is defined as *"[s]ediments that act as both the reservoir and the source for hydrocarbons*" (Boyer et al. 2011). Resource plays differ from conventional plays in the sense that they cover a wide area and are generally not confined to a specific geologic structure (Boyer et al. 2011).

The classification and definitions of oil or gas resources and reserves are often not well defined, and classification systems vary with different global regions. In short, categorization takes place according to the certainty of existence and probability of profitable extraction (IEA 2013). A conceptualization of the abstract sizes of technically and economically recoverable resources and proven reserves is presented in Appendix A.

Apart from North America, other major shale resources are estimated for South America, Asia, Europe, Africa and Australia. A map showing the location of assessed shale gas basins as well as those locations for which the resource size have been estimated is included in Appendix A.

Technology description

Drilling for shale gas and experimentation with drilling techniques gained momentum in the U.S. towards the end of the 20th century (NETL 2013), and the U.S. is still home to most commercial shale gas production. The technological and knowledge advances that contributed to the commercial viability of shale gas were the ability to drill horizontal wells followed by multi-stage hydraulic fracturing stimulation (Boyer et al. 2011; Zou 2013). Both horizontal wells and the creation of fractures increase the exposed surface area of the shale formation. By the start of the new millennium, the production of shale gas had significantly increased. An example of the drastic nature of this increase is the existence of eight unconventional wells in 2005 in the Marcellus play in Pennsylvania compared with 7234 wells in this play eight years later (Brantley et al. 2014). Figure 2.5 shows the layout of a typical shale gas well pad during the drilling and hydraulic fracturing stages.

The exploration stage itself might involve seismic surveys as well as drilling and fracturing of a number of wells to characterise the reserve. If after exploration a shale gas reserve is deemed economically viable, shale gas production process consists of multiple further development stages and activities (Steyl et al. 2012; Esterhuyse et al. 2014).

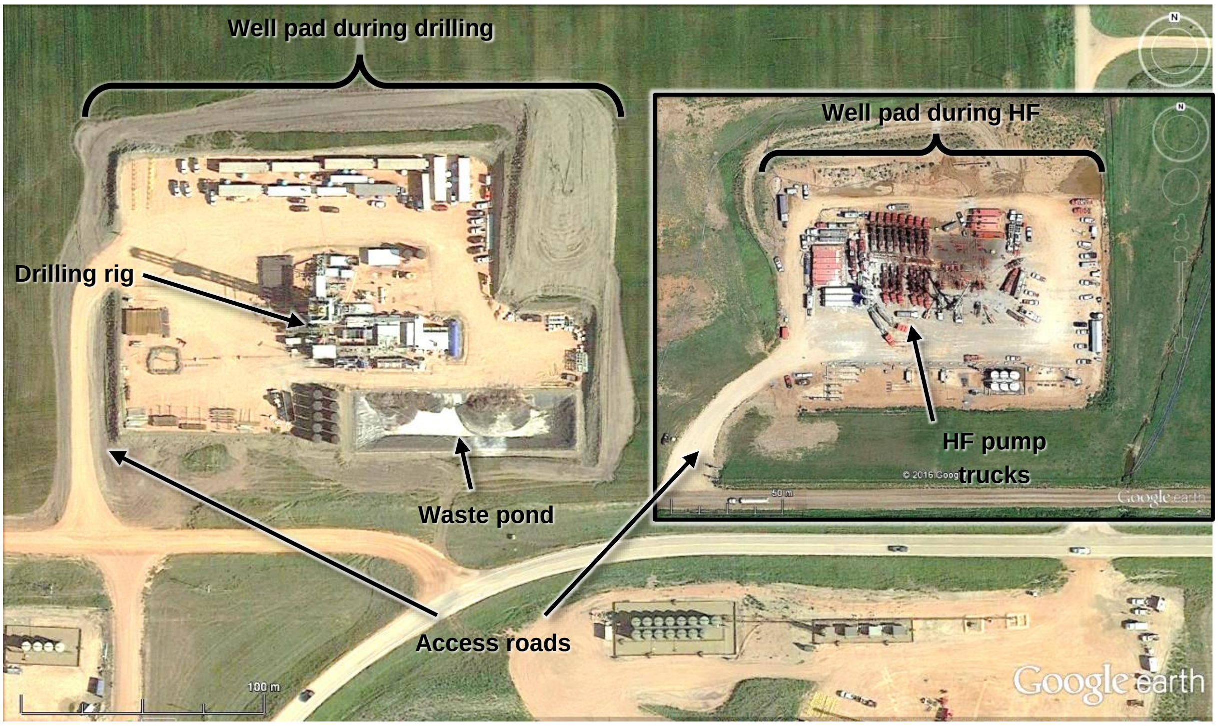


Figure 2.5 A satellite image of a single well pad near Keene, North Dakota (Imagery dated 16 August 2013) during the drilling stage (left) and an insert (right) of a well pad near Geary, Oklahoma during the hydraulic fracturing stage (Imagery date: 27 July 2015). Most prominent facilities are indicated in each image. Photo credit: Google Earth.

From preparation to actual gas production, shale gas development is an intricate process. Due to the uniqueness of each shale gas reserve in terms of location and characteristics of the shale formation, they each possess equally unique characteristics and operational challenges. A high-level description of the on-site activities follows here. Prior to shale gas production, appropriate drilling sites need to be selected based on surveys and studies of geological characteristics such as formation depth and potential intrusions that might influence shale gas potential (de Kock et al. 2016). These sites, between one and two hectares in size, need to be cleared in preparation for drilling and access roads need to be constructed. Boreholes (vertical and often horizontal) are drilled and borehole casings are then installed before the drilling rig is removed. In some instances, six to eight wells are drilled on a single well pad; this is referred to as 'pad drilling' (Speight 2013), and the multiple well pads across an area are collectively known as the 'wellfield'. In preparation for hydraulic fracturing, the walls of the borehole casings are perforated with small explosive charges with a perforation gun. Hydraulic fracturing pumps are then inserted into the boreholes which pump hydraulic fracturing fluid at very high pressure into the targeted shale, creating fractures in the rock. Hydraulic fracturing fluid (also referred to as 'slickwater') consists of 98% – 99.5% water and proppant (usually sand, ceramic partials or bauxite) (Vidic et al. 2013) and 0.5% – 2% additives. The proppant in the hydraulic fracturing fluid holds the fractures open for natural gas to escape. The hydraulic fracturing pumps are then removed, and the flow-back water is contained in waste pits or tanks. The physical preparation and finalization of the borehole, or 'wellbore' as some refer to it, might in itself consist of several sub-stages where water is mixed with either hydrochloric (or muriatic) acid or slickwater. After excess proppant and debris is removed from the wellbore, a wellhead is installed to extract the gas, and the well is closed once production is finished (Steyl et al. 2012; Holloway & Rudd 2013). The layout of a horizontal borehole is illustrated in Figure 2.6, which represents the below-ground activity a well pad such as that seen in Figure 2.5.

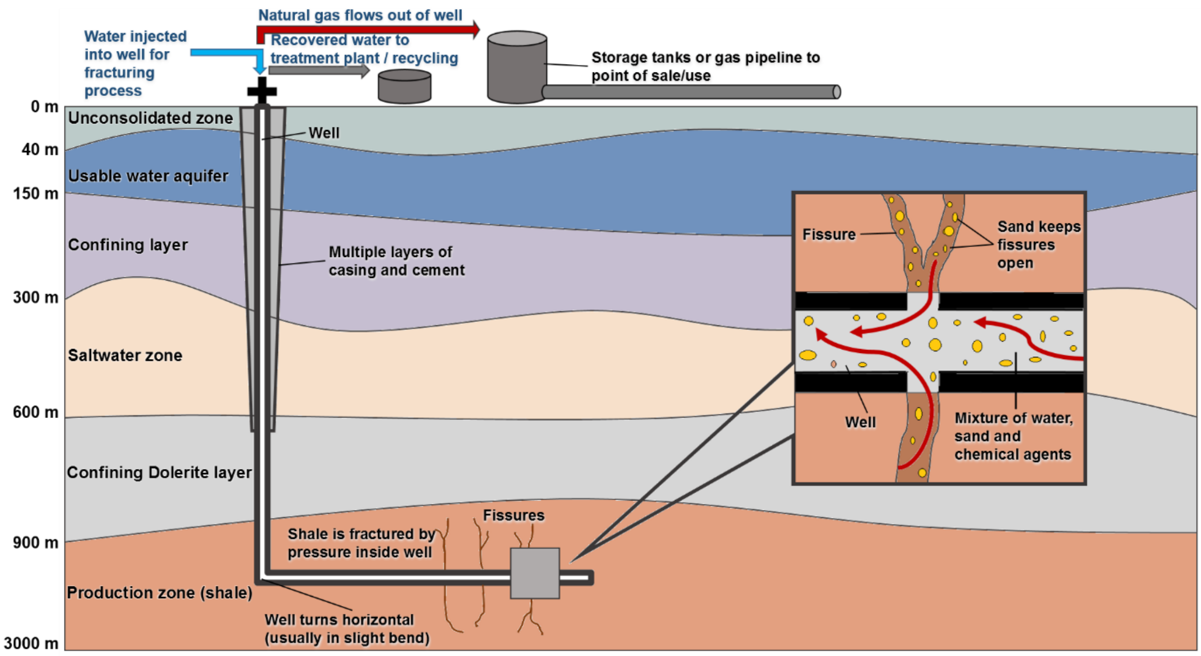


Figure 2.6 A simple diagram illustrating the basic components of the hydraulic fracturing process. A water-sand-chemical mixture is injected down a well at high pressure causing the shale to crack. The fissures are held open by the sand while natural gas flows to the surface through the well. The underlying geology and depth will vary for specific scenarios. Diagram not to scale. As amended from ProPublica (n.d.) and Steyl et al. (2012).

Known characteristics of the Karoo Basin

The shale gas resource size in the Karoo Basin of South Africa currently remains unknown, but could be the eighth largest after the U.S., China, Argentina, Algeria, Canada, Mexico and Australia, according to the latest assessments by Kuuskraa et al. (2013). These authors conducted a study for the U.S. Energy Information Administration where they assessed 137 shale formations in 41 countries, out of which estimates of the various formations within the Karoo Basin have been made. The Prince Albert, Whitehill and Collingham formations belonging to the Permian-age Ecca shale group are believed to hold the majority of shale gas in the Karoo Basin, regardless of previous estimates of the resource size in South Africa varying quite significantly. Kuuskraa et al. (2011) suggest a total of 485 Tcf technically recoverable shale gas, which is adjusted to 390 Tcf by the same authors in 2013 (Kuuskraa et al. 2013). A recalculation of the initial estimates of Kuuskraa et al. (2011) by PASA suggests that technically recoverable gas-in-place may be in the range of 30-500 Tcf (Decker & Marot 2012).

Due to induced gas generation from the shale layers at the time of intrusion, the presence of intrusive Dolerite sills throughout the largest part of the Karoo Basin (approximately 390 000 km^2) possibly poses a threat to the estimated gas resources in the above- and underlying shale formations (Svensen et al. 2007). Apart from the impact of Dolerite sills on potential shale gas, such horizontal intrusions have proved to be rewarding groundwater exploration targets (Chevallier & Woodford 1999). This finding poses another risk of wells acting as artificial connections between associated shallower (<300 m) aquifers (Steyl et al. 2012). Other varying geological factors which could impact the basin's resource size and hydraulic fracturing plans are variation in shale depth and thickness (Svensen et al. 2007), connectivity of fractures, Dolerite dykes (Woodford & Chevallier 2002), geological stresses, total organic content and the thermal maturity of the shale (Decker & Marot 2012; Geel et al. 2013). Further emphasis on the influence of various factors that affect the resource availability is an outcome from a study by Scheiber-Enslin et al. (2013). These authors provide a comprehensive and integrated study that reflects the known borehole, seismic and magnetic data of the Karoo Basin.

Further than estimates of the total resource size, focussed studies have assessed core samples from boreholes at specific locations across the Karoo Basin. In one such study by Geel et al. (2013), two boreholes were drilled near Wolwefontein in the Eastern Cape to obtain samples from the Prince Albert, Whitehill and Collingham formations. The samples varied with regards to the compound types and total organic carbon, and they were found to be thermally over-mature (*i.e.,* the formation was exposed to high temperatures which reduced hydrocarbon generation potential), as a result of having been affected by the Cape Fold Belt, and unlikely to hold gas. This study indicates that the shale gas resource might be smaller than originally anticipated, but encourages future investigations to continue the assessment of the potential for shale deposits towards the north of the region.

In 2015, both the Karoo Research Initiative's (KARIN) projects for boreholes KZF-1 in the Tankwa Karoo and KWV-1 near Willowvale in the Eastern Cape were drilled, and early results show that neither indicated definitive positive prospects for shale gas. The final depth at KZF-1 was 671 m. Here, unexpected structural complexity was encountered with regards to the duplication of the Whitehill and Prince Albert formations, but that of the Collingham formation was as expected. Initial analysis of the core samples revealed 'negligible' amounts of desorbed gas, but the volume and methane content of residual gas in the Whitehill formation were deemed of particular interest due to the potential for gas release when fractured. One shallow aquifer was encountered at 60 m and three artesian flows at 558 m, 625.5 m and 671 m; the first and the last of these were fresh water and the second sulphurous. The water from the fresh artesian flow was of good quality compared to that of the area's shallow aquifers (de Kock et al. 2016). At KWV-1, the final depth of the borehole was 2353.48 m, and the target formation was found 600 m deeper than expected. There was no indication of free or residual gas, and the formation quality was of high maturity. It was concluded that the shale gas potential in that part of the Karoo Basin is essentially zero. A number of existing boreholes were sampled to determine the baseline conditions of shallow groundwater aquifers within a 10 km radius. Initial results indicated that the water is of good quality based on pH and electoral conductivity measurements, but full results must still be analysed and released (de Kock et al. 2016). The results from these two boreholes '*cast doubt'* on the initial estimates of the resource size, but research is scheduled to continue in other areas throughout the Basin (Caboz 2016). Furthermore, the unexpected artesian flows of relative good quality fresh water might affect motivation to proceed with hydraulic fracturing in the studied areas.

The environmental impacts of shale gas production

Natural gas is a versatile fuel and energy source for a variety of uses, and it is considered to be a 'cleaner' alternative to other fossil fuels such as coal and oil in terms of carbon emissions (Spellman 2012). Others argue that the methane emissions associated with natural gas and the hydraulic fracturing process has a much larger greenhouse gas footprint than conventional oil and gas (Howarth et al. 2011). Such controversies about almost all impacts of shale gas extractions are common, and studies of this nature are being published on an increasing scale (Kerr 2010; Nicot & Scanlon 2012; Cohen & Winkler 2014). Although shale gas and oil extraction with hydraulic fracturing have driven the recent energy boom in the U.S., a range of possible environmental risks are frequently questioned (Davies et al. 2014). These are discussed in the rest of this sub-section.

Some authors analyse the life cycle impacts of shale gas, including all energy, water and material acquisition needed from pre-production up until well closure. Throughout the entire shale gas life cycle (*i.e.,* from exploration to production), most of the impacts appear to be associated with the horizontal drilling- and hydraulic fracturing stages (Branosky et al. 2012). Sub-components of shale gas LCAs such as GHG emissions are also used to compare to that of other energy resources on bases of equal energy units (Jenner & Lamadrid 2013). The expected environmental impacts of shale gas development varies over the stages of exploration, construction, hydraulic fracturing and production activities (Brittingham et al. 2014; Krupnick et al. 2015; Holness et al. 2016), and ecosystem-specific impacts depend on the resource characteristics and location (Brittingham et al. 2014). However, due to the large quantities of water required by the hydraulic fracturing process, the impact of shale gas development on water resource availability and quality is a primary concern (Donaldson et al. 2013; Mauter et al. 2014). The experience of shale gas impacts on water resources in Pennsylvania is frequently mentioned in literature (Vidic et al. 2013; Warner et al. 2013; Brantley et al. 2014). The estimated water requirement per well is 10 000 – 20 000 m^3 for the life-time of the well (De Wit 2011). In turn, the duration of the well life time depends on the resource size and economic optimization. When breaking down the water requirements per well, approximately 1000 m^3 is needed for the drilling activities and 11 150 – 16 300 m^3 (this amount depends on whether water is available for re-use or not) for the hydraulic fracturing. The source of water to meet these requirements for shale gas production in South Africa is unknown as potable groundwater in the Karoo is already severely constrained, and there is limited potential to develop non-potable groundwater resources. Furthermore, the impacts of wellfield development, transport and storage on water resources have to be taken into account together with the direct water usage requirements (Hobbs et al. 2016).

Esterhuyse et al. (2014) list and describe the biophysical aspects that could be adversely impacted by shale gas extraction with hydraulic fracturing in South Africa. These aspects include surface water, groundwater, seismicity, vegetation, soil, air quality, aquatic invertebrates, terrestrial insects, mammals, fish, amphibians and reptiles (Esterhuyse et al. 2014). The various adverse impacts on these biophysical entities are discussed in relation to whether they occur during shale gas exploration, during extraction and/or after extraction. Of all the biophysical entities, the study finds that surface water, groundwater and vegetation are expected to be critically impacted as those provide the necessary habitat and infrastructure for all terrestrial and aquatic fauna.

In the U.S., issues relating to shale gas production and the associated environmental impacts and concerns have been documented since 2005, one year after drilling started in the Marcellus formation in Pennsylvania (Brantley et al. 2014). In addition to the shale gas experience in the U.S., Canada, Argentina and China are the only known countries commercially producing shale gas. However, as of late 2015, at least Mexico, Colombia, Algeria, Germany, Poland, Russia and the United Kingdom have also undergone shale gas exploration with minor production in some countries not yet reaching commercial status (Kuuskraa et al. 2013; U.S. EIA 2016).

Krupnick et al. (2015) conducted structured surveys with stakeholders from four groups in the U.S. on the topic of environmental risk pathways associated with shale gas development; the four groups were non-government organizations, industry, academics and government. Participants were asked to prioritise various risk pathways associated with the environmental impact of shale gas (e.g., the effect of flowback water on groundwater resources). From these, consensus pathways were identified with the associated activities, environmental burdens and impacts; *i.e.*, pathways on which agreements were reached between stakeholder groups. These are shown in Table 2.4. Depending on the source of water to be used for hydraulic fracturing in South Africa, the impacts may not be identical to the pathways shown in the table. However, the routine risk pathways (as arising from "*everyday operations and risks arising from accidents"* (Krupnick et al. 2015)) during the various activities and development sub-stages (e.g., site preparation) should arguably not be much different.

Table 2.4 High-priority environmental risk pathways associated with shale gas development that were agreed upon by non-government organizations, industry, academics and government. As amended from Krupnick et al. (2015).

Routine Risk Pathways	Environmental Burdens	Impacts
Site preparation		
Land clearing and infrastructure construction	→ Storm water flows → Habitat fragmentation	→ Surface water → Habitat disruption
Drilling		
Venting of methane	→ Methane	→ Air quality
Casing and cementing	→ Methane	→ Groundwater
Fracturing and completion		
Use of surface water and groundwater	→ Fresh water withdrawals	→ Surface water → Groundwater
Storage of fracturing fluids	→ Fracturing fluids	→ Surface water
Venting of methane	→ Methane	→ Air quality
Storage/ Disposal of Fracturing Fluids and Flowbacks		
On-site pit/pond storage	→ Flowback and produced water	→ Surface water → Groundwater
	→ Fracturing fluids	→ Surface water
Treatment by municipal water treatment plants	→ Flowback and produced water	→ Surface water
Treatment by industrial water treatment plants	→ Flowback and produced water	→ Surface water

Apart from the high quantity of water needed for shale gas development, the treatment and disposal of waste fluid generated by drilling and hydraulic fracturing is regarded as a significant challenge (Brantley et al. 2014). Residual wastewater from shale gas developments collectively refers to drilling fluids, fracturing fluid, flowback water and produced water (Warner et al. 2013). These waste fluids are often high in saline, contain toxic metals and are radioactive (Rowan et al. 2011; Vidic et al. 2013). The management of wastewater from oil and gas activities in the U.S. includes recycling for future hydraulic fracturing, disposal by injection into deep wells, treatment at publically or commercially owned treatment works or wastewater treatment plants, or use for dust suppression on roads. Furthermore, in some instances several of the disposal options are associated with environmental concerns or are prohibited in some areas (e.g., geology not favouring deep-well injection or prohibition of spraying wastewater on roads or land) (Warner et al. 2013). Appendix B gives a summary of common chemical additives used in fracturing fluid as well as commonly occurring components in flowback water. The impact of shale gas production on water is relatively well-published (e.g., Mauter et al. 2014; Brittingham et al. 2014; Brantley et al. 2014; Vidic et al. 2013). However, access to reliable water quality and incident data, which enables comparison of the spatial and temporal impact of shale gas development and examples of incident impacts, is found to be a hindrance to in-depth assessment of the issue (Brantley et al. 2014).

Shale gas production in Canada started slowly in 2005 and the total number of unconventional wells has increased exponentially since 2008. A moratorium has been in place since 2014 in selected Canadian shale basins, which was not yet lifted at the time of writing. Apart from radioactive waste material, atmospheric and audial impacts and induced seismicity, water quantity and quality impacts are the main environmental concerns. Across Canada, the reported water usage per well varies between 2000 m^3 and 100 000 m^3 and the recovery of flowback water also varies from 15% – 100% across the different areas (Rivard et al. 2014). Examples of two incidents related to hydraulic fracturing included inadequate well casing which led to contamination of a shallow water-bearing formation and an extensive spill of flowback fluid affecting a surface area of 4.5 ha. This was reported to be cleaned up before seepage could occur. Ongoing research on the environmental aspects of shale gas are also predominantly focused on the potential impacts on groundwater and induced seismicity from waste water injection (AER 2011; AER 2012). The Council of Canadian Academics also addressed the environmental impacts associated with shale gas developments in Canada. The lack of available information about key issues, the inability to obtain relevant data and variation in data quality were noted as key considerations impacting the interpretations of their findings. However, groundwater resources and greenhouse gas emissions, both related to well integrity, were found to be the most concerning issues related to shale gas extraction (CCA 2014).

Publications on the impact of shale gas production on water resources in the U.S. are increasing (e.g., Warner et al. 2013; Mauter et al. 2014; Brantley et al. 2014) with some coverage in Canada (Rivard et al. 2014). However, peer reviewed literature on the environmental impacts of shale gas in Argentina and China were not available at the time of writing.

Shale gas development in the United Kingdom has not yet entered commercial production and was limited to exploration at the time of writing. Nonetheless, a study by The Royal Society and the Royal Academy of Engineering was done to investigate the possible environmental impacts of shale gas (The Royal Society & Royal Academy of Engineering 2012). The study concluded that there is much overlap between the environmental impacts of shale gas development and conventional oil and gas activities, and such impacts can be managed by means of effective regulation and continuous monitoring. Concerns related to aquifer contamination, naturally occurring radioactive materials (NORMS) and induced seismicity are also considered manageable in the presence of continuous risk assessment. Ensuring well integrity was identified as a high priority in preventing contamination. Additional water requirements are also considered manageable through an integrated approach which includes practices such as recycling and reuse. The uncertainty of the scale of future shale gas activities and the possible additional demand for regulatory capacity were acknowledged.

Habitat fragmentation, pollution risks and impact on water resource availability and quality are thus the greatest concerns related to shale gas production as they have the potential to cause local and regional disturbances in ecosystem functioning and community composition (Brantley et al. 2014).

2.5 Study area: South Africa's semi-arid interior

Solar power developments and planned shale gas developments in the Karoo Basin are largely located across the country's semi-arid interior. This broader study area includes part of the Savanna biome but predominantly overlays the Nama-Karoo.

2.5.1 Overview of the land use in the broader study area

The Nama-Karoo and Savanna biomes jointly cover approximately 60% of South Africa's surface area (SANBI 2012). This area coincides with the northwestern part of the country, which broadly represents the areas identified with favourable solar resources. Areas which shale gas exploration right applications have been received are located towards the southern interior, also mostly representing the Nama-Karoo. According to the latest national land-cover dataset based on the Landsat 8 imagery of 2014, these arid areas are almost entirely classified as either 'Low shrubland', 'Bare ground' or 'Erosion' (DEA 2015).

Studies on the impact of other anthropogenic disturbances in the arid regions of South Africa are relatively common, the most popular of which is livestock farming (e.g., Hanke et al. 2014). Unsustainable livestock farming practice is the most prevalent anthropogenic disturbance in the semi-arid and arid ecosystems of South Africa; it is also considered the most dominant driver of land degradation, which is defined as a decrease in both biodiversity (Sala et al. 2000) and productivity (Adeel 2005). Studies have been conducted on land degradation (Hoffman & Ashwell 2001), land-cover and ecosystem services (Reyers et al. 2009) and grazing systems (Beukes et al. 2002) in these two biomes. However, given the relatively recent decision to include renewable energy sources into South Africa's electricity generation system, studies on the environmental impact of solar power developments in South Africa are only now emerging and thus harder to find in the literature.

The study area, along with the rest of the surface area of the country not specifically relevant to this study but with potential for renewable energy and shale gas development, has been included in Strategic Environmental Assessments (SEAs) by the Department of Environmental Affairs (DEA) and the Council for Scientific and Industrial Research (CSIR) (CSIR 2014; CSIR 2016b). Although the outcomes of SEAs are not enforced, they do provide guidance in identifying areas optimal for a particular planned development (e.g., renewable energy) (CSIR 2013).

The Square Kilometer Array (SKA) project is also located in the broader study area and is one of the Strategic Integrated Projects identified in the National Development Plan (NPC 2012). Similar to planned energy developments in this region, the SKA offers a range of potential impacts, both positive and negative, on the biodiversity and ecology of the area. These were identified through an SEA done for the SKA from 2015 to 2016 (CSIR 2015c).

The study area is home to a number of protected regions, including private nature reserves, biosphere reserves and national parks (DEA 2016). According to the latest National Protected Areas Expansion Strategy, the Nama-Karoo and Savanna are areas allocated for future protection (SANParks 2010). However, to properly plan for conservation areas, sufficient data of the existing biodiversity is needed, and the reality is that not all areas are equally sampled. Some areas within the Nama-Karoo have never been sampled by botanists but are designated as top priority for botanical sampling in South Africa's latest Plant Conservation Strategy (Raimondo 2015).

The current level of formally protected land in the Nama-Karoo is particularly low, making much of the land available for development activities. Table 2.5 summarises the percentage of conservation estate within the two biomes, which is a combination of protected areas (e.g., nature reserves and national parks) and conservation areas (e.g., biosphere reserves and conservancies).

Table 2.5 The conservation estate within the Nama-Karoo and Savanna biomes by major categories (DEA 2016b; SANBI 2012).

	Nama-Karoo	**Savanna**
Conservation areas	0.49%	19.23%
Protected areas	1.37%	15.77%
Total conservation estate	**1.86%**	**35.00%**

In light of planned renewable energy, uranium mining and hydraulic fracturing, Milton and Dean (2015) describe arid ecosystems such as the Karoo as 'power factories'. These authors further argue that instead of contributing to the degradation, which has already occurred from agriculture, future developments should be incentivised to invest in simultaneous restoration in order to conserve these unique ecosystems.

2.5.2 Landscape dynamics in the study area

As examples of influences and dynamics covering the larger study area, ecosystem services and climate change are briefly discussed below to provide an outlook of the ever-changing landscape within which energy developments are planned.

Ecosystem services

The loss of biodiversity, which is usually linked with development, is of singular concern because of its importance within both human-managed and natural ecosystems, but ecosystem services also fundamentally rely on biodiversity (Mace et al. 2012). According to the Millennium Ecosystem Assessment of 2005, human wellbeing is described in terms of five aspects: health, social relations, security, material needs for life and freedom to act and choose (MA 2005). This links closely to the rights related to the environment outlined in Section 24 of the Constitution of South Africa as stated earlier. Human wellbeing is thus directly or indirectly linked to ecosystem services, and these services are influenced by the multitude of factors influencing foundational natural resources (Scarlett & Boyd 2015). 'Supporting services' is regarded as an overarching ecosystem service category, while provisioning-, regulating- and cultural ecosystem services have a more direct impact on humans.

Reyers et al. (2009) investigate impacts on ecosystem services in the Little Karoo following changes in land-cover. Ecosystem services are based on the pristine condition of an area. According to data available at the time, the ecosystem services were found to be 18% – 44% lower than their theoretical potential. Regulating and supporting services such as carbon storage and water-flow regulation were found to have declined the most, and land degradation associated with livestock grazing and area clearing was the major driver of decline in ecosystem services. Considering these ecosystem services form the foundation of the agricultural economy of the area, these findings should be a concern for the potential influence on long-term productivity and resilience of the region. Home to vulnerable people, ecosystems and services, this overall decline can become problematic in semi-arid systems across the globe; the Little Karoo is just one example (MA 2005).

Egoh et al. (2009) find a positive correlation between areas with high biodiversity and ecosystem services across the biomes of South Africa and highlight the importance of biodiversity protection. Although the focus of this study excludes socio-economic impacts, the potential impact of development such as solar power plants and shale gas production on natural systems has the potential to influence the ecosystems' ability to offer valuable ecosystem services (Dale et al. 2011).

Climate change

Dale et al. (2011) argue that land use, energy systems and climate change are interlinked and that any analysis of the role of one of these in landscape ecology should be supported by at least the awareness of the others. The biophysical characteristics of an area within which energy developments are currently planned are thus not necessarily an indication of the future characteristics of the same area. Throughout the past decade, notwithstanding the long lead periods associated with climate change research, studies related to climate change in the arid biomes of South Africa have increased (Masubelele et al. 2015; Moncrieff et al. 2015; Midgley & Thuiller 2011); this also links into the functioning of ecosystem services. As elaborated on by Bourne et al. (2016), a better understanding is needed of the short- and long-term impacts of climate change on ecosystem functioning to make use of ecosystem-based adaptation. This understanding will help people identify priority areas where adaption is needed to buffer the impacts of climate change.

The Quiver tree (*Aloe dichotoma*) presents a species-specific example of the impact of climate change in the study area. The number of studies on the Quiver tree has increased due to the impact of climate change on populations in the arid Namaqualand and Bushmanland regions (e.g., Guo et al. 2016). The Quiver tree has been added to the 'flagship fleet' of the IUCN to 'share the burden of the polar bear' in creating climate change awareness (Barua et al. 2011). This species' sensitivity to changes in environmental factors plays a key role in its susceptibility to climate change, especially during the juvenile period (Foden et al. 2007). However, the more recent findings of Jack et al. (2016) suggest that anthropogenic climate change is merely one of a number of factors which should be considered as cause for observed Quiver tree mortality. The possible example of the Quiver tree serves as a valuable alert to the value of ecosystem-based adaptation in land use planning and the need to be cognisant of the land use, climate change, energy nexus (Dale et al. 2011; Bourne et al. 2016). Future energy developments might thus be located in areas which are currently not ecologically sensitive, but such status could change depending on the extent of impacts from climate change.

2.5.3 Spatial datasets representing study area

The EIA Regulations under NEMA (Act no. 107 of 1998) list and describe activities that can potentially impact the surrounding environment and their associated assessment reports. These reports are required for either a Basic Assessment or for a Scoping and full Environmental Impact Assessment. For both types of reports, the receiving environment needs to be described prior to the commencement of the activities being assessed. Descriptions are primarily based on desktop identification of the geographical location and other "*physical, biological, social, economic and cultural aspects which may be affected by the*" planned development/proposed activity (DEAT 2012). This initial identification makes use of spatial biodiversity and environmental datasets to determine baselines for the environment (DEA 2016a), expediting the environmental impact identification process (Jordaan 2009) and providing a starting point to identify the need for specialists. The South African National Biodiversity Institute's Biodiversity GIS website makes a wide variety of province specific and national spatial datasets available for download (SANBI 2016). The National Vegetation Map (SANBI 2012) and the Protected Areas Database of South Africa (DEA 2016b) are two examples of spatial datasets used for this purpose. The same or similar datasets were used for the preliminary site selection of at least one of the prospecting oil and gas companies who applied for a shale gas exploration right in the Karoo Basin (Golder Associates 2013).

Considering the important role spatial datasets representing biodiversity play in preliminary impact assessment and identification as well as national conservation planning (Reyers et al. 2007), one would expect reliable and high quality datasets. However, compiling and updating datasets for equal representations across biomes and vegetation types requires significant coordinated effort, which is not always possible due to cost and time restrictions.

2.6. Impact assessment methods

A true reconciliation between economic growth, development and conservation of global biodiversity calls for environmental analysis that is not limited to unnaturally imposed boundaries such as development fences but rather follows a resource-based approach (Treweek 1999). The EIA process is the current regulatory method to assess the impact of developments on the environment in South Africa. The legislation that guides this process has been described in section 2.3.1. In addition, a number of the most commonly used impact assessment approaches are described below, all of which are limited in scope.

2.6.1. Environmental Impact Assessment

The application of EIA within legal frameworks that integrate sustainability matters and environmental concerns with development planning dates back to 1969 when it originated as part of the National Environmental Policy Act of the USA (Wathern 1988). Most developing countries have adapted the EIA framework as first described in 1969 to their administrative, political, technical and socio-economic context (Bekhechi & Mercier 2002), including South Africa.

As described in section 2.4, South Africa's EIA process is governed by law, and activities require either a basic assessment or a full EIA depending on how the specific activity is listed. All socio-economic, cultural and environmental impacts are assessed in these EIAs and, depending on the context of the activity, require the input from appropriate specialists (RSA 2014).

EIA is the broader approach that includes social and economic considerations and the potential impact which development activities may have on these. Ecological Impact Assessment (EcIA) is a more specific approach focusing on environmental impacts and separated from other impacts such as social, economic and heritage resources. The demand for both the EIA and EcIA as environmental management tools is growing rapidly as pressure on natural resources increases and biodiversity progressively becomes more threatened.

"*Ecological impact assessment is a formal process of defining, quantifying, and evaluating the potential impacts of defined actions on ecosystems*" (Treweek 1995). Similar to EIA, EcIA has its origin in U.S. legislation. In 1969, U.S. legislation mandated EIAs, which was the start of a global adoption of EIA techniques. Based on key ecosystem components with an understanding of the interactions between one another, unlike EIA, proper implementation of the EcIA process is said to provide an ecosystem management approach which is scientifically defensible. Another difference from EIA, is that EcIA can be applied on a range of scales, be it at a localised individual project level or through regional development actions (Treweek 1999). The bulk of experience in EcIAs, however, has been gained through the application thereof as part of an EIA practice, and literature on the subject is seemingly limited to the work of Joanna Treweek (Treweek 1995; Treweek 1996; Thompson et al. 1997; Treweek 1999).

Enquiry into the South African EIA process has been included in the investigation in this thesis as it is the current legislated approach towards identifying environmental impacts associated with developmental activities.

2.6.2. Strategic Environmental Assessment

Being complementary to the EIA process, 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 is that an EIA highlights both negative and positive impacts at project level. SEA aims to improve strategic (Therivel 2012) action where the best suited development activities and areas are matched prior to development proposals; therefore, the SEA includes a landscape level approach (DEAT 2004).

Two additional overarching roles that a SEA can play are in advocating for raising the profile of the environment and in integrating where the focus is on combining social, economic and environmental considerations. The SEA process is not specifically defined, but it is continuously evolving and adjusted according to the intended role SEA needs to play within specific circumstances (DEAT 2004).

In South Africa, a SEA was performed by the CSIR for wind and PV power to determine Renewable Energy Development Zones (REDZs) where "large scale renewable energy projects would have lowest negative environmental impacts while yielding the highest possible social and economic benefit to the country" (CSIR 2013). Following on this SEA for wind and PV power, a SEA was performed for the future of the transmission grid development (CSIR 2015a). This planned development was based on the requirements of three scenarios within the IRP, and five Transmission Power Corridors were identified. The five main corridors are Northern Import, Central, Eastern Coastal, Western Coastal and the Solar Corridor. The Solar Corridor is almost entirely located in the North West and Northern Cape Provinces. The SEA for Shale gas development (SEASGD), which was under way at the time of writing, is the first collaborative study to look into the holistic and collective impact that shale gas development might have in the study area as well as the rest of the country (CSIR 2015b).

Although SEA is a higher level approach intended only as guidance, impacts at local and project levels could be minimised by narrowing down sensitive and/or no-go areas following a top-down approach. Figure 2.7 illustrates how SEAs and EIAs are positioned relative to one another and policy.

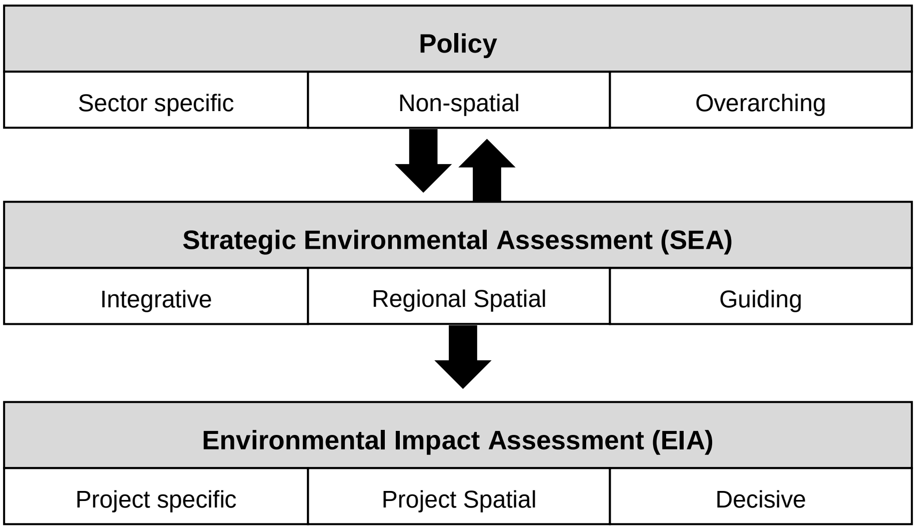


Figure 2.7 An illustration of how Policy, SEAs and EIAs fit together with regards to specificity, spatial application and implementation (as amended from CSIR 2014).

2.6.3. Life Cycle Assessment

A Life Cycle Assessment (LCA) includes all impacts from material production to end-of-life, also termed ‘cradle-to-grave’; but the scope can also be adjusted to focus on certain stages of a service or product (Klöpffer 1997). A LCA has been applied to thoroughly investigate and compare different land-usage between electricity generation technologies (e.g., Fthenakis & Kim 2009). This method can be extended to analyse other effects of a technology’s life cycle such as water-use, emissions and resource depletion (Klöpffer 1997). A possible shortcoming of the LCA methodology lies with quantifying longer-term secondary effects such as cumulative soil and/or water contamination and ecosystem disruptions arising from such secondary effects. As mentioned in earlier sections, LCA studies have been done for the energy technologies included in this study and have been noted to vary in depth and scope (Fthenakis & Kim 2010; Burkhardt et al. 2011; Klein 2013).

2.6.4. Modelling

Land use change models have been used increasingly for integrated impact assessment, visualization and quantification of land use change, analysing biophysical and socio-economic system properties, and decision-making. However, limitations related to time-frames and the dynamic nature of social and environmental interactions seem to be an area where improvement is needed (Veldkamp & Verburg 2004). Based on how other impact assessment methods/tools are specified in terms of spatial and temporal scope, potential future value exists in the application of integrated or pure modelling to the impact of utility-scale energy projects on the natural environment.

Different model types are categorised as either hardware, conceptual or mathematical models; the latter of these is further categorised as either probabilistic or deterministic. A conceptual model is used to express concepts regarding the expected significant components and processes within a system, and it also provides an outlook on how these might be connected. Although models can be very abstract, they can also be as one-dimensional as a map. Maps and data are used in geographical information systems (GIS), as conceptual models are very useful in monitoring biospheric and geospheric states. Mathematical modelling of the environment on the other hand, can be applied to various systems within ecosystems such as energy balances, biochemical cycles, water cycles and life cycles. Within these systems, states, relations and dynamics are aspects within ecosystems that can be further distinguished based on variables within the systems (Hugget 1993). Furthermore, mathematical modelling of human impact on the environment will always include spatial or temporal variable(s) depending on the purpose of model (Hugget 1993). Such variables theoretically make modelling an ideal approach to capture ongoing change in a defined area such as the impacts imposed by energy developments in arid landscapes.

2.6 Conclusion

The literature included here aims 1) to provide the necessary context to the diversification of South Africa's energy system and 2) to provide an introduction into the impacts of solar power and shale gas developments in the South African landscape whilst being cognisant of the legislation and policy driving these developments.

It was highlighted how ecosystems within the Nama-Karoo and Savanna represent subsystems within a larger 'holistic system', comprising development goals, politics, global trends towards alternative energy and socio-economic factors at various administrative levels. Energy developments, guided by the location of high quality solar resource and the potential distribution of shale gas, present the introduction of a new suite of environmental impacts in the arid biomes of South Africa. Current assessment methods of these environmental impacts are well-covered in terms of legislation. No literature, however, is available for the impact of the experienced and prospective impacts of these developments locally. Considering the wide spatial distribution of these developments, cumulative and/or longer-term impacts might be a challenge deserving specific attention. The assessment of the impacts of energy developments across the study area thus provides an opportunity to enter a novel research field as well as enable proactive and strategic land use and resource planning.

CHAPTER 3: THE IMPACTS OF SOLAR POWER

The number of operating solar power plants in South Africa has increased significantly since 2013, and several more have been planned and/or committed to with the start of commercial operation pending (Eberhard et al. 2014). Approximately 70% of these projects are located within the semi-arid Northern Cape (DEA 2016), introducing a novel fleet of infrastructure into the landscape of this province that is mostly represented by the Nama-Karoo and Savanna biomes (Mucina & Rutherford 2006). This chapter presents the direct impacts of these power plants as collectively experienced by interviewed experts, observations during site visits and spatial analysis.

3.1. Introduction

3.1.1. Solar resource distribution and solar power capacity allocation

Milton and Dean (2015) recognise the current trend towards energy resource use in arid biomes such as the Nama-Karoo and Succulent Karoo and describe these landscapes as 'power factories'. Using several examples in the U.S. (Lovich & Ennen 2011), desert landscapes are being regarded as ideal for the location of large-scale solar power developments due to lower human population density and frequent cloudless days (Levitan 2013). Although not classified as true deserts, this description holds for at least two arid biomes in South Africa where two solar power technologies are being deployed.

High quality solar resources are distributed across South Africa's north-western interior, providing an opportunity to increase the contribution from concentrating solar power (CSP) and photovoltaic (PV) power to the country's energy mix (WWF-SA 2015). Although slightly different in their 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 (Banks & Schaffler 2006; Pfenninger et al. 2014). Solar resource, measured in Direct Normal Irradiation (DNI) for CSP technology and Global Horizontal Irradiation (GHI) for PV technology, guides the location of these solar developments. Maps illustrating the distribution of DNI and GHI across the study area are included in Appendix C.

As outlined in Chapter 2, capacity allocated to CSP and PV are included in the Integrated Resource Plan (IRP) of 2010 and the draft IRP Update of 2013 (IRP Update) as contributors to South Africa's electricity generation capacity by 2030 (Department of Energy 2011; Department of Energy 2013b). This capacity is implemented through bidding rounds of the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP). At the time of writing, four bidding rounds have occurred, with 600 MW committed to CSP and 1899 MW to PV power projects; a fifth REIPPPP bidding round was being concluded at the time of writing (DOE 2016). The capacity allocated to CSP is distributed across seven individual projects of which two are central receiver plants and five are parabolic trough plants (NREL 2016); capacity allocated to PV power throughout the first four rounds of the REIPPPP is distributed across 45 developments of which the majority are fixed-tilt plants and a smaller number have single- or dual-axis tracking technology. All CSP developments are located in the Northern Cape to date. The majority of PV plants are also located in the Northern Cape, but a few developments are distributed across five other provinces (DOE 2016).

Suitable locations for the abovementioned solar power plants are chosen based on numerous criteria. Ideal locations for wind and PV plants in South Africa have been highlighted through the Strategic Environmental Assessment (SEA) for national wind and solar PV conducted by the Council for Scientific and Industrial Research (CSIR) to determine Renewable Energy Development Zones (REDZ). The aims here are to minimise negative environmental impact and maximise socio-economic benefits. Regardless of these identified areas, obtaining access to an unsaturated part of the transmission grid remains a major challenge faced by renewable energy developers in South Africa (Council for Scientific and Industrial Research 2014a). As a result, some solar power projects are not located within the identified zones. The ideal locations of CSP plants have not been included in the SEA as have been for wind and PV, but Fluri (2009) identifies the Northern Cape as the most popular province for this technology when taking solar resource, land use profile, slope and proximity to transmission lines into account. The Upper Orange water catchment area (DWAF 2004) has been identified as having the highest potential for those solar developments requiring water consumption. The water requirements for CSP might thus be a restricting factor in the Northern Cape, depending on power cycles and which cooling technology is used. Due to the different resource needs and the subsequent distribution of CSP and PV plants, there is an inevitable variation in the associated footprints on different vegetation types and biomes across the landscape.

By July 2016, there were two operational CSP plants in South Africa: 100 MW Kaxu Solar One near Pofadder and 50 MW Bokpoort parabolic trough plants (NREL 2016b). The 50 MW Khi Solar One central receiver plant is in the process of being commissioned, and no local or long-term impact studies are available to inform optimal CSP plant design and operational procedures in the country. The difficulty in finding recorded data thus provides an early opportunity for studies like this to assist with planning for potentially more significant future impacts arising from a larger fleet of CSP plants which contribute to baseload electricity generation as described by Pfenninger et al. (2014).

3.1.2. Development area and expected environmental impacts of solar power development

Existing anthropogenic activities in the country's semi-arid central region, largely representing the Nama-Karoo and Savanna biomes (Mucina & Rutherford 2006), predominantly consist of agricultural and mining related activities (Hoffman & Ashwell 2001). Natural disturbances include impacts of fire, frost and drought (Hoffmann et al. 2002). The generation and evacuation of electricity from utility-scale power plants thus provides a new suite of impacts and changes in the land use within the aforementioned region. These impacts can be classified as direct (e.g., water usage during operation) or indirect (e.g., emissions from manufacturing of power plant components prior to construction), but also adverse (e.g., avian mortality) or beneficial (e.g., CO_2 emissions avoided) (Turney & Fthenakis 2011). Of these, the adverse direct impacts are likely to be the most controversial in impact assessment reports and international reviews (Hernandez et al. 2014) and remain the focus of this chapter. As mentioned in Chapter 2, different impacts are presented by the two CSP technology types: parabolic trough and central receiver plants. The impacts associated with PV developments overlap with that of CSP in some categories, but in others (e.g., impact on water resources) there is a marked difference between technologies (Tsoutsos et al. 2005). The layouts of these developments are also inherently different as can be seen in Figures 2.2 and 2.3.

Internationally, research on the environmental impact of solar power in forms other than that of Life cycle Assessments (LCAs) of CSP and PV plants has not been published extensively (Turney & Fthenakis 2011), and findings from Environmental Impact Assessments (EIAs) remain with the Environmental Assessment organization representing the developer and the authorised government department. However, studies like this might support the foundation on which the legal requirements for EIAs are made. Considering the potential for solar power in South Africa, an investigation of the technologies' impacts on the surrounding natural environment represents a reasonable starting point towards reconciling protection goals for their development and the environment as set out in the National Development Plan (NPC 2012) as well as measures that prevent contributing to climate change.

3.1.3. Chapter objective

The aim of this chapter is to investigate the direct environmental impacts of known allocated CSP and PV power projects and capacities across the Nama-Karoo and Savanna biomes. The first objective was to investigate potential differences in impacts between power plant development stages and the sufficiency of the current EIA process to cover these. The secondary objective was to determine to what extent these impacts will change in the landscape over time, considering the multi–megawatt allocations to these technologies in the IRP2010 and IRP Update. Multiple factors determine future developments and the locations thereof, so analysis towards the second objective was limited by the available information. Results and recommendations concerning management and mitigation measures of these impacts are elaborated on in Chapter 6.

3.2. Method

As quantitative and qualitative data about the biophysical environment and social experience was required, a mixed-method research approach (Driscoll et al. 2007) was followed to conduct primary research by collecting data through interviews and site visits as well as from spatial datasets. The combination of different research instruments provided an indication of the direct environmental impacts of solar power development from a literature, experience and spatial-perspective. Figure 3.1 gives an outline of the approach that was followed in this chapter.

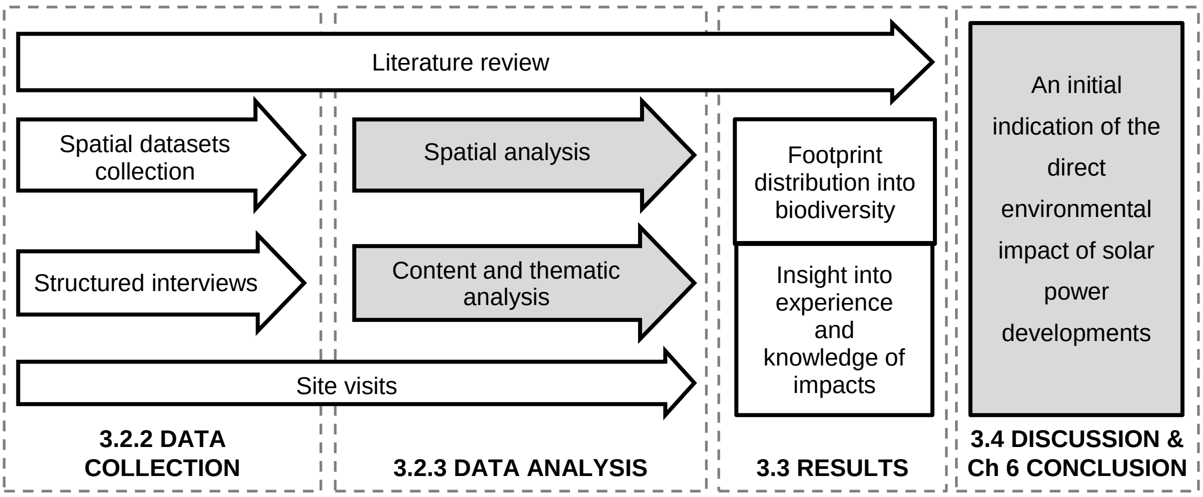


Figure 3.1 A schematic illustrating the mixed-method approach, an indication of the sub-sections where these are described and where the results and discussion are presented.

3.2.1. Study area

All existing South African CSP power plants are located in the Northern Cape. PV power plants are distributed over six provinces with 62.5% of the projects located in the Northern Cape and the remaining located across the Western Cape, Limpopo, Free State, Eastern Cape and North West Province (DEA 2016). Apart from the availability of solar resource, the availability of capacity on the national transmission grid is a determining factor of where solar power developments are located.

The mean annual rainfall in the Nama-Karoo is between 100 mm and 520 mm. In the Savanna biome, rainfall varies between 235 mm and 1000 mm due to the biome's distribution from the sub-tropic northeast towards the drier northwest (SANBI n.d.). Two towns situated near several CSP projects, Pofadder and Upington, have mean annual rainfall values of 92.7 mm and 150.6 mm respectively (Dean & Milton 1999). The Orange River plays an important role for at least the location of CSP projects in the study area due to the need for water in the power cycles, contributing to the current limited location of CSP projects.

The Eastern upper Karoo, Bushmanland Arid Grassland and Northern Upper Karoo are the three most extensive vegetation types within the Nama-Karoo. Many of these types within this biome have a large dwarf shrub component; this is especially seen in the southern regions. Towards the north, grasses and low-growing trees occur throughout irregular plains (Mucina 2006b). The geology within these vegetation types is mostly represented by shales and mudstones with dolerite intrusions. Soils here vary from red and structureless to that with high lime and salt content. Compared to the Nama-Karoo, which is limited to the central part of the country, the Savanna biome has a wider distribution that extends from the northern and northeastern parts of the country to some parts of the east coast (see Figure 3.2). In the Northern Cape, the most prominent Savanna vegetation types are the Gordonia Duneveld, Kalahari Karroid Shrubland and

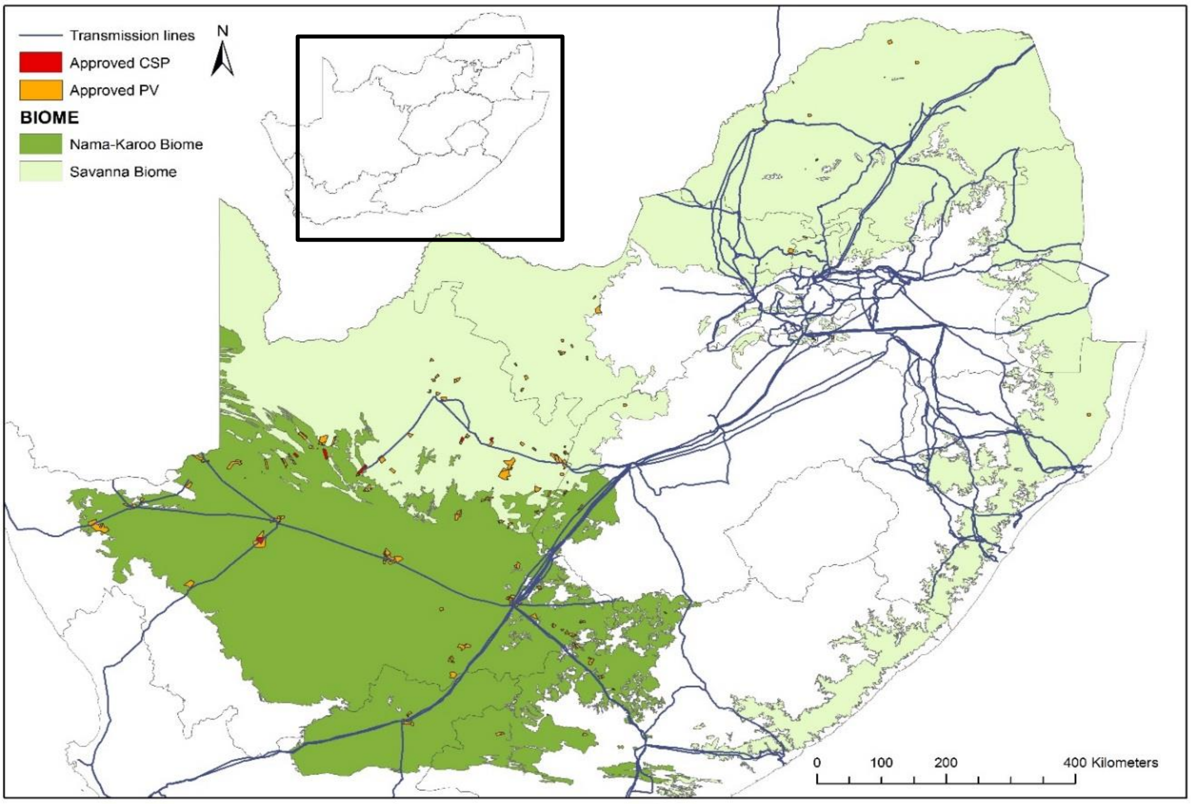


Figure 3.2 A map of the Nama-Karoo and Savanna biomes where the red and orange areas show the distribution of approved EIA applications for CSP and PV developments respectively. The national transmission grid is also shown.

the Gordonia Plains Shrubland. Plains with a grass- and tree layer and occasional shrubs are a common sight in the northern parts of the Northern Cape. Silcretes and calcretes are common in the underlying geology of this area, and sand dunes or sandy soils are widely distributed (Mucina & Rutherford 2006). The Nama-Karoo and Savanna biomes are shown with approved EIA applications for solar power developments in Figure 3.2.

3.2.2. Data collection

Structured interviews

Between February and May 2016, structured interviews were conducted with individuals experienced with or knowledgeable about the EIA process in South Africa and/or the environmental impact of solar power. Although the interview form mostly consisted of specific sections with structured questions, some questions were open-ended (an outline of the sections is presented in section 3.3.1). This form was used to obtain qualitative and quantitative data; a copy is included as Appendix D. Ethical clearance was obtained for the interview process from the Departmental Ethics Screening Committee of the Department of Conservation Ecology and Entomology before the start of the interview process. Interviewees were informed that the interview results will be used in this thesis and also signed a consent form.

Criterion sampling, a purposive sampling approach (Bryman 2015), was used to identify individuals as candidate interviewees from predetermined expert groups. A minimum criterion for interviewees was knowledge of and/or experience with the environmental impact of solar power in South Africa. Snowball sampling, where an interviewee enabled the introduction to another interviewee, was also used to identify further potential interviewees. Noy (2008) regards snowball sampling as a way to dynamically both investigate and produce knowledge.

Prior to the interviews for this study, an unofficial pilot study of the interview process was conducted where two individuals with knowledge on the research topic were interviewed. The purpose of the pilot study was to improve the structure, format and questions of the interview form prior to the actual interviews with the expert groups (Babbie 2010).

Interviews were requested with individuals from the following predetermined expert groups: environmental impact practitioners, researchers, specialists, relevant government department employees, state-owned utility employees, relevant employees of independent power producers. These individuals make up a representative sample of the greater knowledgeable and experienced population of experts on the environmental impact of solar power (Babbie 2010; Picardi & Masick 2014). To contribute to the sample description of the interviewees, information related to experience and education was recorded in an early section of the interview form (Appendix D).

In total, 20 interviews were conducted in English in which responses were given regarding the environmental impact of solar power. There was a different number of responses for CSP (n=14) as compared with PV (n=11), but some interviewees responded for both CSP and PV (n=5). In certain cases, interviewees also qualified for more than one expert group. Conducting the interviews in-person was the preferred method, but where circumstances prohibited this, interviews were conducted telephonically or via internet video conference. The duration of interviews varied between three-quarters of an hour to one and a half hours. Interviewees were asked to respond only to questions with which they were confident and/or comfortable. Responses were recorded in English as text directly onto an electronic copy of the interview form during the interview. This copy of the interview form was then used as a transcript for analysis.

Site visits

Observation, as a simple nonexperimental method, enables the examination of dynamics and experiences in real-time. To support the findings from the interviews, a field trip was included as part of the data collection where personnel and activities were observed obtrusively (*i.e.,* aware of the researcher's presence) in a naturalistic setting (*i.e.,* on-site of power plant developments whilst day-to-day activities continue) (Picardi & Masick 2014).

This field trip occurred in June 2016, during which four PV plants and two CSP plants were visited. The purpose was to observe the status and environmental impacts of existing solar power developments in person. This was done through on-site observations and walk-arounds, interactive discussions, photographic recording where it was allowed, and asking practical questions based on the interview form structure. All hosts were informed of the purpose of the visit and agreed to share information accordingly. Site 2, an operational PV site near Hanover, was the only site where no photographs were allowed.

Figure 3.3 shows the location of the power plants which were visited and the descriptive information for the different power plants is included in Appendix E. Accompanied by the co-supervisor of this study on the fieldtrip, field notes were made while hosted and escorted around on the development sites.

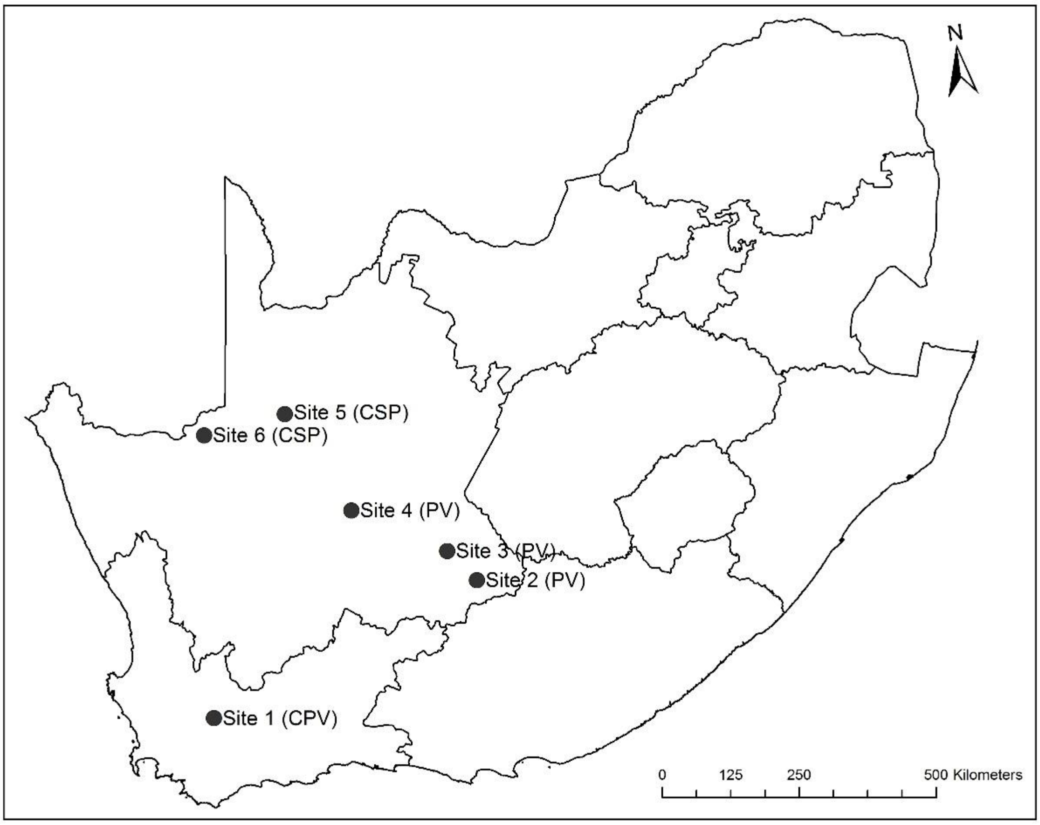


Figure 3.3 The locations of the solar developments visited during the field trip. At the time of the site visits, sites 4 and 6 were under construction, sites 1, 2 and 3 were in full or partial operation, and Site 5 was being commissioned.

Spatial datasets

Spatial datasets that summarise EIA applications for CSP and PV (hereafter, the EIA dataset) were obtained from the Department of Environmental Affairs. This EIA dataset was used as the primary reference to identify areas where CSP and PV developments are taking place and where impacts as explored through the interviews are experienced.

To obtain a regional understanding of the impacts experienced from these developments, the locations of CSP and PV developments were used to investigate impacts on the landscape by using a combination of topic-specific spatial datasets. The majority of these datasets is publically available and/or obtained from researchers in Government Departments with permission to use. Table 3.1 summarises the titles and sources of these data sets.

Table 3.1 A summary of the spatial datasets used for the spatial analysis of the footprint of solar power developments with a short description of each and the respective sources.

Title of data set and year published ***Description***	**Source (Reference where different from source)**
South African Renewable Energy EIA Application Database Q1 2016 *Project-level spatial data regarding EIA applications received for renewable energy developments.*	(Department of Environmental Affairs 2016c)
National Vegetation Map (Vegmap) 2012 *An update to the 2006 version of the same spatial dataset, describing floristically based vegetation units of SA, Lesotho and Swaziland.*	(South African National Biodiversity Institute 2012)
South African Protected Areas Data Base Q1 2016 *Spatial dataset of the conservation estate of SA, including both formally protected areas and areas with a lower level of protection.*	(Department of Environmental Affairs 2016b)
Important Bird Areas 2015 *The Important Bird Area (IBA) Programme is an International BirdLife programme to conserve important bird habitats. These areas are determined based on guidelines and criteria for species occurring in the area.*	(BirdLife South Africa 2015)
National Protected Areas Expansion Strategy: Focus areas for protected area expansion 2010 *Areas identified through a systematic biodiversity planning process to determine large, unfragmented and intact areas very important for ecological persistence and biodiversity presentation.*	(South African National Parks 2010)
Strategic Water Source Areas 2013 *SWSA are identified for South Africa, Lesotho and Swaziland and are areas supplying a disproportionate amount of annual runoff to geographical regions of interest.*	(Council for Scientific and Industrial Research 2013b)
DEA Solar PV SEA Phase 1 Study Areas *Renewable Energy Development Zones (REDZs) developed to indicate areas with top PV power development potential. These areas were identified taking into account the following: network losses and capacity, social need, solar resource availability, protected areas, special land uses, geographical features such as slope.*	Department of Environmental Affairs (CSIR 2013)

3.2.3. Data analysis

Structured interviews

Responses from the interview forms were captured in Microsoft Excel or directly into the Computer Assisted Qualitative Data Analysis Software (CAQDAS) ATLAS.ti 7® (Friese 2014) in preparation for analyses.

Qualitative data were subjected to content analysis by coding responses given for the different sections of the interview form. Coding is a method for defining what qualitative data is about in order to analyse the data. Simply put, coding involves identifying and highlighting parts of text, pictures or recordings that resemble a similar theoretical or descriptive concept. The collection of highlighted or identified data parts are then linked via that concept referred to as a 'code' (Gibbs 2007).

Depending on the type of analysis used, interview data can be subjected to various cycles of coding in order to organise and analyse the findings. A combination of initial or open coding and structural coding were used for the first cycle coding (Saldana 2013). The first cycle coding involved selecting responses to certain sections of the interview form as a 'quotation' after which a code is linked to that quotation (Gibbs 2007). Second cycle coding involved deductive categorisation of different topics intended to be addressed through the interview process. But it also involved inductive categorisation of codes based on patterns that emerged from responses to open ended sections of the interview form (Saldana 2015). Second cycle coding thus assisted in the identification of different categories from the grouping of related codes.

After the categorisation of codes into sub-themes/categories, simple content analysis was done, which laid the foundation for thematic analysis (Joffe & Yardley 2004). Thematic analysis involved the discussion of categories and responses/codes within categories with the highest frequency of occurrence. Coding and categorisation resulted in these categories being grouped into four emerging themes. Figure 3.4 is a conceptual process tree showing how interview data was coded and categorised for thematic analysis.

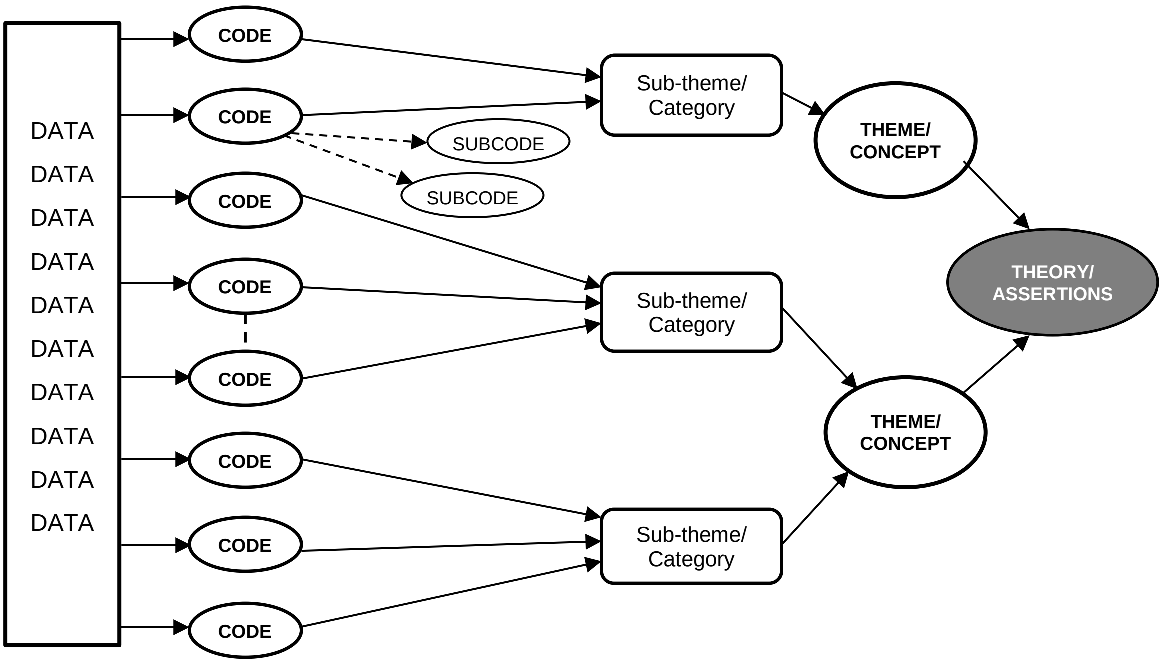


Figure 3.4 A conceptual illustration of how coding of qualitative data from the interview process was coded and analysed as amended from Saldana (2015).

To determine the reliability of a researcher's code application (e.g., Picardi & Masick 2014), Joffe and Yardley (2004) regard inter-rater reliability as a stronger test than code-reapplication where the same researcher re-codes at two distinct occasions. Coding reliability was tested by providing another researcher with an opportunity to code the responses to a sample of the interview forms. The average similarity between the allocated codes and that of the second researcher was 80.8%. This figures seems high, however, several different methods and metrics are used for calculating inter-rater reliability (e.g., Gwet 2008) and the author has not explored this result further.

The quantitative analysis was limited to questions in the interview form where 'yes' or 'no' were the only possible answers and to Section 4 in the form (Appendix D) where numerical scores were obtained by rating the 'severity' and 'physical scale' of impacts. The latter ratings were given for the impacts of power plants on different biophysical elements and impacts from distinct solar power plant components on the biophysical environment as a collective. Ratings from zero to five were given for the construction and operational stages of a solar power development. The results for CSP and PV were recorded separately here. For convenience, the descriptions associated with the ratings obtained in Section 4 of the interview form are given with the findings in section 3.3.1.

The aforementioned ratings represent ordinal-scale data (Stevens 1946), which had a non-normal distribution. The relatively small sample size ($10 \geq n < 20$) with the aforementioned data scale and distribution characteristics rendered the non-parametric, Mann-Whitney U test (Cohen & Holliday 1996) appropriate for comparing ratings between the different stages of solar power (construction and operation). The calculated probability values (p-values) from the Mann-Whitney U test were used to test for statistical significance in the ratings between the different development stages (Lavrakas 2008). 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 (Buskirk 2008).

The results from Section 4 in the interview form were thus used a) to test for a significant difference in the rated severity and physical scale of impacts on biophysical elements during construction versus operation stages using the Mann-Whitney U test and the associated p-value (McKillup 2006) and b) to compare the ratings for severity and physical scale of biophysical impacts and power plant components during the respective stages of the solar power development. For the abovementioned a), the null hypothesis assumed no significant difference between the rated severity and physical scale of impacts on various biophysical elements during construction and operation. For b), the null hypothesis assumed no significant difference between the rated severity and physical scale of impacts by different power plant components. All statistical analysis was done using the Microsoft Excel statistical plugin, XLSTAT® (Addinsoft 2015).

Site visit findings

Experience data obtained from six site visits to solar power plants have been interpreted in the context of each unique power plant, and no additional analysis was done. The purpose of the site visit data was primarily to support the findings from the interviews, which is discussed in this context in section 3.4.1.

Spatial data

Preparation for spatial analysis required that all spatial datasets be projected to an appropriate coordinate system. The Albers Equal Area projection with the Hartebeeshoek94 reference geographic system was used as it preserves required geometrical features for spatial analysis (DRDLR 2013). The GIS software package, ArcGIS®, was used to conduct all spatial and geographical data analysis. Appropriate tools from ArcGIS were used to manipulate and combine datasets as well as extract information that reveals insight into the impact of solar power developments across the Nama-Karoo and Savanna biomes using the solar power EIA application areas as starting point.

3.3. Results

3.3.1. Interview results

Expert groups selected for the interview process were represented by the following entities: the Solar Thermal Energy Research Group (STERG) at Stellenbosch University, BirdLife South Africa, Council for Scientific and Industrial Research, ESKOM, Department of Environmental Affairs (DEA), the South African National Energy Development Institute (SANEDI), World Wide Fund for Nature South Africa (WWF-SA), Umvoto Africa (Pty) Ltd, the Plant Conservation Unit at the University of Cape Town, Simon Todd Consulting, Khi Solar One (Pty) Ltd (Abengoa), Golder Associates Africa (Pty) Ltd, Savannah Environmental (Pty) Ltd. Not all interviewees were comfortable with disclosing their affiliations. The number of responses which were obtained from the different expert groups for CSP and PV is summarised in Table 3.2. Some interviewees represented more than one expert group.

Table 3.2 A summary of the representation of the interviewees and the number of responses for the two solar power technologies.

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

The highest relevant qualifications of the interviewees were primarily in the fields of Environmental management, Geology or Geo-hydrology, Conservation Ecology and Environmental science; these were distributed as follows: 10% Honours level, 60% Masters level, 30% PhD or higher.

Through the coding and analyses of the interview data from all interviewees (n=20), it was found the responses can be summarised through the categorisation of codes into four prevailing themes. Results for themes one to three are presented below; results for theme four make up the basis for discussion in Chapter 5. The sub-themes/categories linked to every theme are also presented in the appropriate section. Figure 3.5 illustrates which interview sections contributed to which of the four themes.

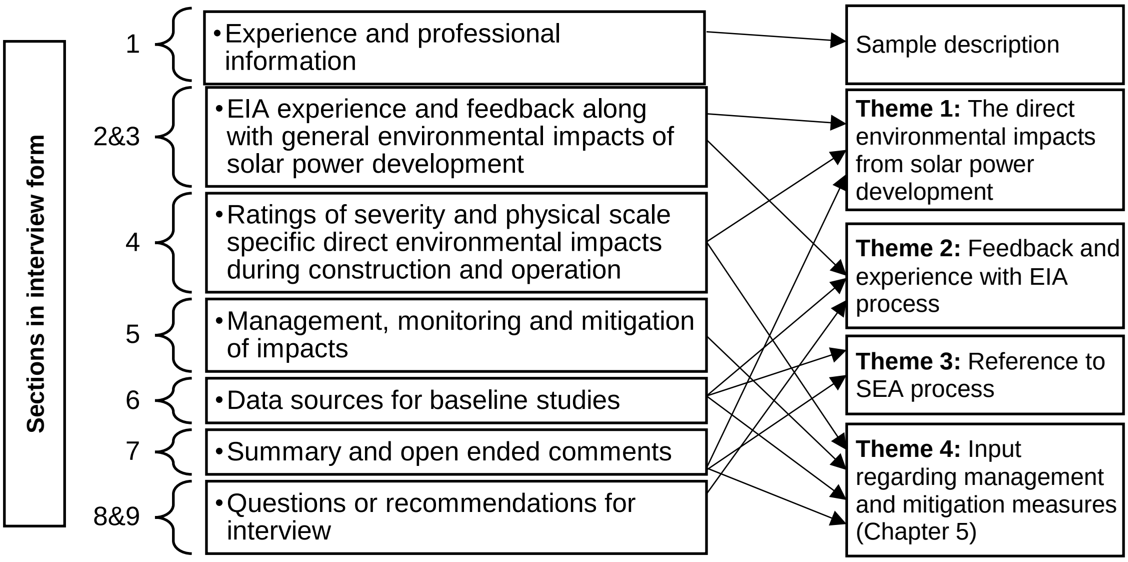


Figure 3.5 A schematic illustrating the contributions from the different sections of the interview form to the four themes.

Theme 1: The direct environmental impacts from solar power development

One of the earliest questions in the interview form asked if interviewees are aware of any adverse direct environmental impacts from solar power developments on the natural environment. To this question, 95% of interviewees (n=19) responded ‘yes’ and 5% of the interviewees (n=1) responded ‘no’.

Interviewees were also given the opportunity to mention any known impacts related to solar power development. Forty seven different impacts were coded in this section. After the second cycle coding, these impacts were reduced to seven biophysical impact categories, which are listed and described in Table 3.3.

Table 3.3 A summary and description of the categories under theme 1, the direct impacts of solar power on the biophysical environment (Biophysical impacts in short).

Biophysical impact category	Description
Atmospheric and audial	Impacts include changes in albedo, micro-climate, audial impact, light pollution and visual impact.
Biodiversity and ecology	Impacts mentioned as 'biodiversity' or 'ecological' impacts and impacts with potential to have an effect on the dynamics between biological and physical ecological proxies.
Fauna	All mentioned impacts with specific relevance to animals.
Flora	All mentioned impacts with specific relevance to plants or vegetation.
Landscape	Impacts on the land which transcends the boundaries of a development or refers to the impact of a development(s) on the landscape.
Soil and/or geological impacts	Impacts by solar power developments on soil and/or the underlying geology.
Water	Resource quality and size related impacts for both surface and groundwater resources.

Figure 3.6 shows the frequencies with which the most common impacts were mentioned within the seven biophysical impact categories. The 'impact on fauna' with a particular focus on avifauna was found to be the most prominent impact category associated with solar power developments, followed by 'landscape impact' and 'impacts on biodiversity and ecology'. On the other hand, impacts on flora and soil or geological impacts were mentioned less frequently during the interviews. More specifically within the given impact categories, one can see that 'habitat transformation or loss', 'visual and dust impacts' and 'impact on total water resource availability' were frequently recorded. The full record of quotations per impact category is included in Appendix F.

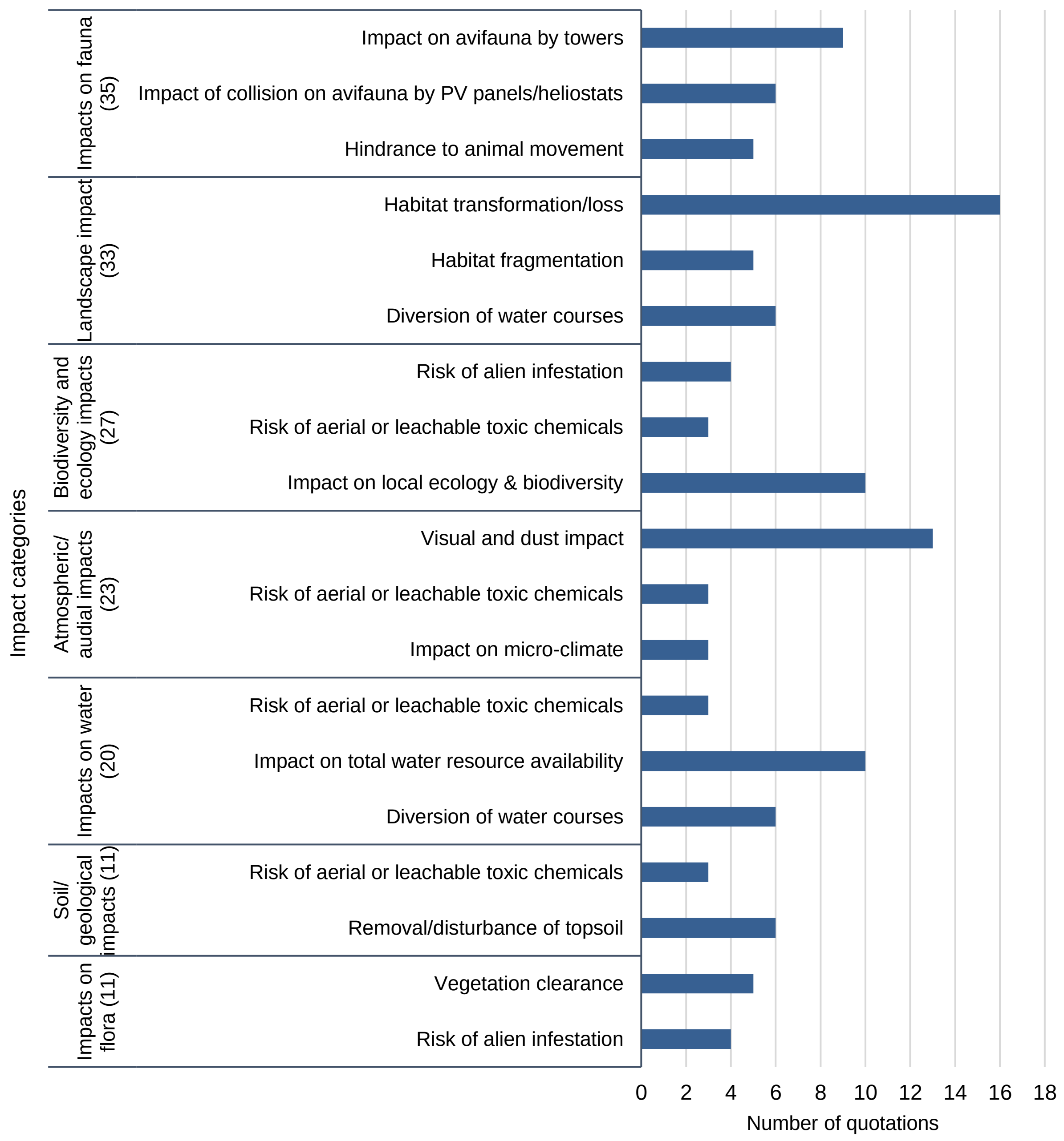


Figure 3.6 Summary of the seven biophysical impact categories in descending order by total number of quotations per category from top to bottom (indicated in brackets). Biophysical impacts that were mentioned more than twice per impact category are listed per impact category. A quotation represents a single event where the specific impact was mentioned.

Interviewees were asked which impacts they regarded as most important at a project(s) where they were involved, after which the following impacts were mentioned: habitat transformation/loss, harm to birds, impact on total water resource availability, impact on local ecology and biodiversity, vegetation clearance, visual and dust impact. Although the impact on water resources was not as frequently coded as that of impacts on fauna, the long-term impact of multiple CSP projects on water-availability was a concern for at least three interviewees. As an example, an interviewee who manages a team of environmental assessment practitioners (EAPs) shared that the water in the Orange River is largely allocated to other uses, and current predictions are that the river is less than 10 years away from not being able to meet further development needs.

The abovementioned impacts were obtained from interviewees as 'impacts of solar power' generally, but interviewees were at liberty to mention impacts specifically related to CSP or PV. Of these impacts, the impact on avifauna from central receiver towers and avifauna collision impacts with PV panels or heliostats from central receiver plants were found to be the most frequently mentioned. The risk of toxicity of the thermal oil of parabolic trough plants and PV panels were also mentioned.

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 separately for CSP and PV. Table 3.4 shows the difference between the numerical scores used for ratings and the associated explanation of the ratings presented to the interviewees. Several interviewees commented that ratings were given here on the assumption that the needed management actions or plans are in place, *i.e.,* if management plans were not in place, a higher rating might have been given.

Table 3.4 An explanation of ratings attributed to the severity and scale of impacts on different biophysical elements and solar power plant components.

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)

Figure 3.7 shows the difference in the medians and ranges (minimum to maximum) of ratings obtained for the two stages of the solar power development for CSP (n=10) and PV (n=13). It is important to note that a score of zero was given by interviewees when they believed the impact was not relevant to the specific technology. These values were removed before calculating the median for each data subset. However, the number of zero ratings is included in tables and plots summarising the number of ratings for each subcomponent of the Section 4 data (shown in Appendix G).

Based on the ratings for CSP, and as shown in Figure 3.7, one can see that the severity of only surface water usage, birdlife and visual impacts was rated higher during operation. The median rating for the severity of impacts on all other biophysical elements is equal to or higher than that of construction. Ratings for the physical scale of impacts on these biophysical elements were found to be similar during the two stages in almost all cases except for groundwater quality where the median rating was higher during construction. Interestingly, for visual impact the range of the ratings for the physical scale of the impact was found to be the highest (min = 2, max = 4) during operation. For PV developments, the median ratings, shown in Figure 3.7, also indicate that severity of impacts are the same for both stages or higher during construction, again with an exception to visual impact which received a higher rating for the operational stage. For both CSP and PV, the highest severity ratings were received for the impacts on soil, vegetation and dust impact during construction.

Table 3.5 summarises the biophysical components and p-values for which a significant difference was found between the construction and operational stages. Here we see significant difference between these two stages for the severity of impacts on almost all biophysical components for PV developments. No significant difference was found for the rated physical scale of impacts between the two stages of development for PV. However, strong evidence of a significant difference between development stages was found for the physical scale of impacts of CSP developments. All calculated p-values for the severity and scale of CSP and PV developments are given in Appendix H.

Table 3.5 The biophysical components for which there was a significant difference in ratings between construction and operation. These are given for severity and physical scale for both CSP and PV. [A] In all these cases, construction ratings were higher than those for operation. Significance values are provided in parentheses.

	CSP	**PV**
Severity	Soil (0.033) Mammals (<0.001) Reptiles (<0.001) Vegetation (0.004) Dust (0.003)	Soil (0.002) Air quality (0.033) Birdlife (0.010) Mammals (0.001) Reptiles (<0.001) Vegetation (0.004) Audial impact (<0.001) Dust (<0.001)
Physical scale	Vegetation (0.011) Dust (0.009)	

[A] Results from Mann-Whitney U test, n=15, p-level (alpha level) used = 0.05. Full results in Appendix H.

Figure 3.8 shows the medians and ranges (minimum to maximum) of the ratings obtained for the severity and physical scale of the impacts from the various power plant components during the two stages of CSP and PV power plant development.

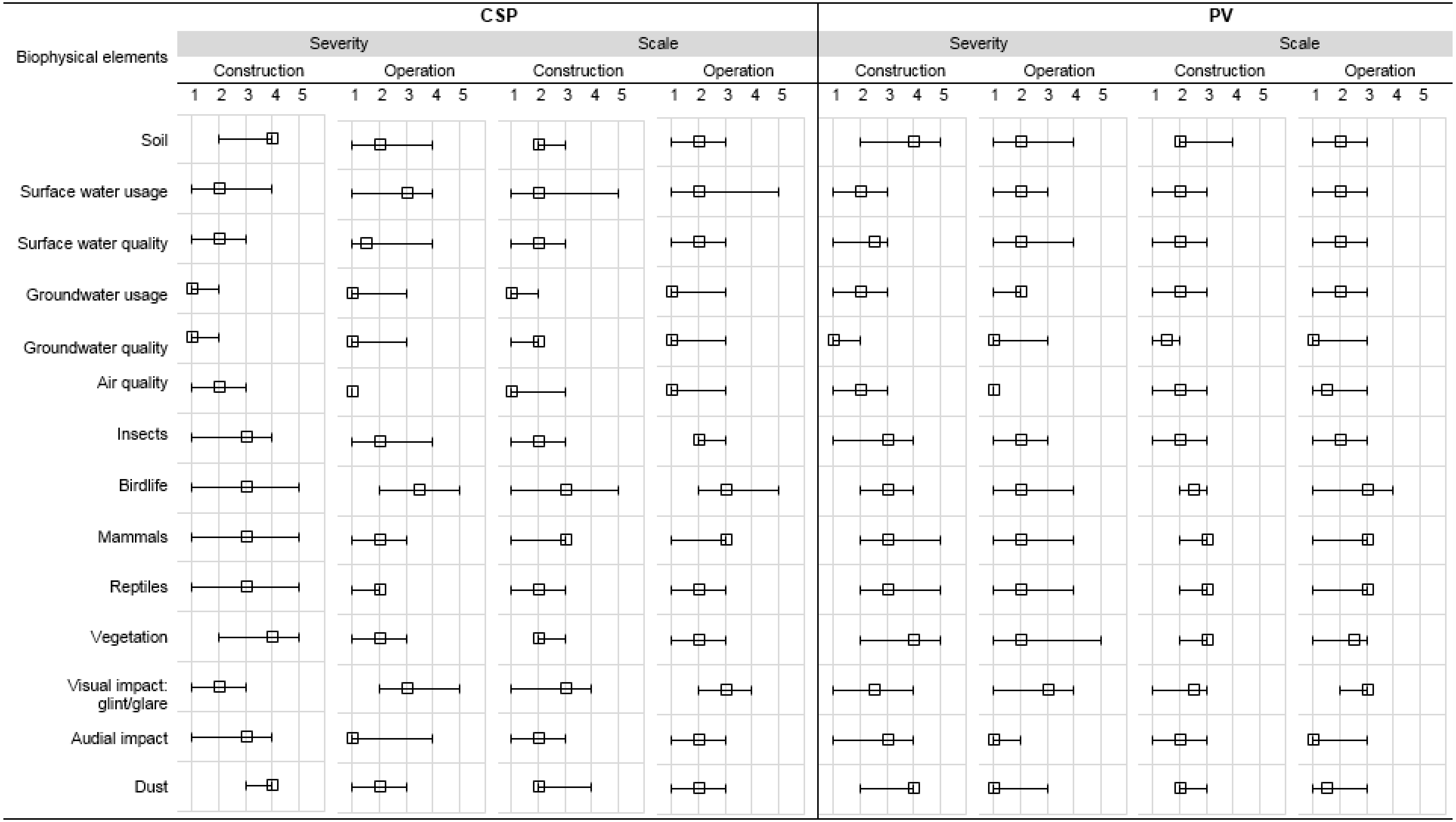


Figure 3.7 The median and range (minimum to maximum) of ratings obtained for the severity and physical scale of impacts on various biophysical elements during construction and operation of CSP (n=10) and PV (n=13) developments. Description of ratings are given in Table 3.4.

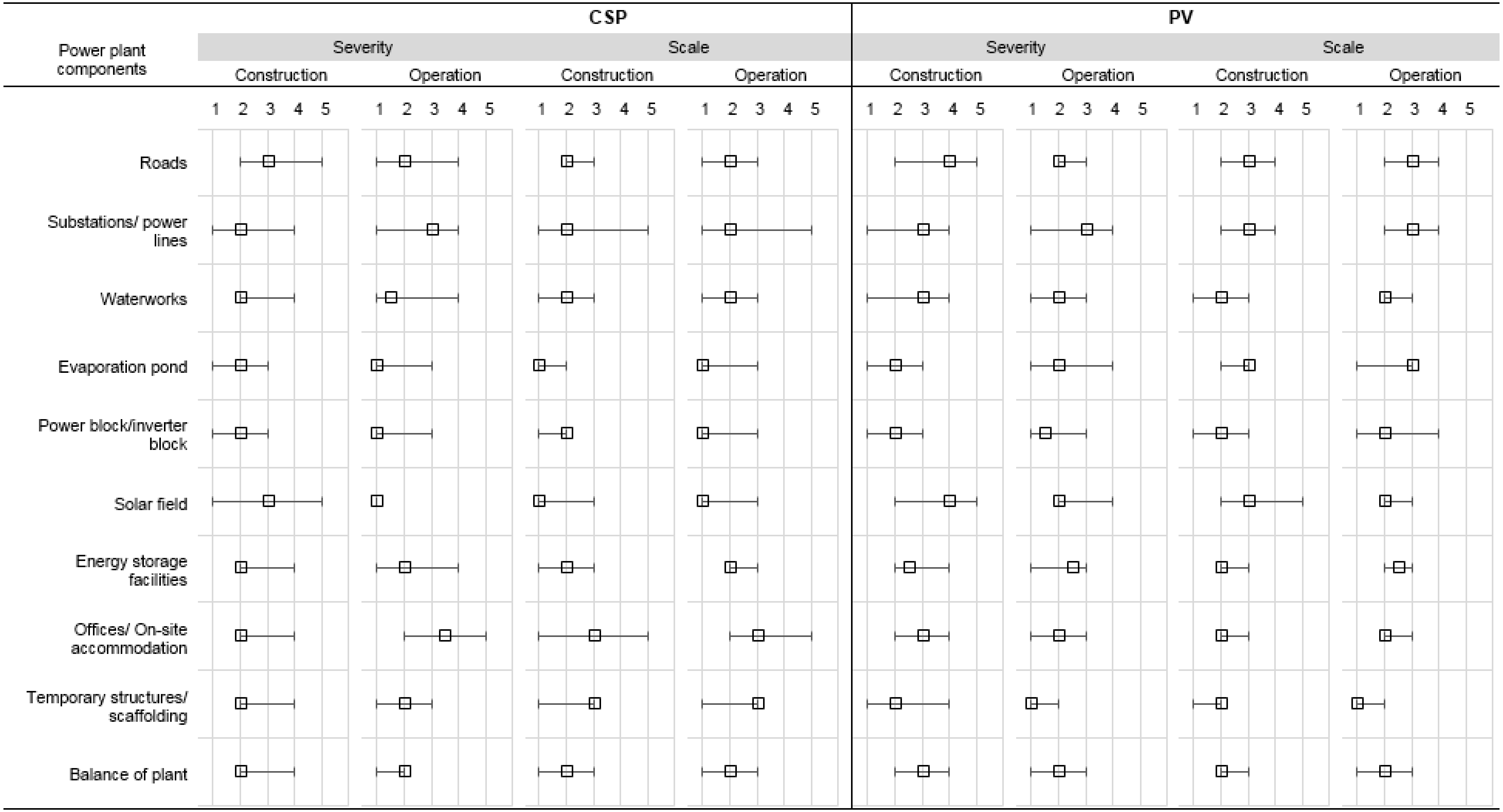


Figure 3.8 The median and range (minimum to maximum) of ratings obtained for the severity and physical scale of impacts from various power plant components during construction and operation of CSP (n=10) and PV developments (n=13). Descriptions of ratings are given in Table 3.4.

From the ratings for CSP, the medians are at a '2' for the majority of the power plant components for both severity and physical scale, with the exception of roads and the solar field for which the severity is rated higher during both stages (Figure 3.8). The physical scale of impacts by substations and/or power lines received higher ratings for either or both stages. The findings for the impacts by the various components of PV developments are similar to those of CSP developments, but an underlying exception is that evaporation ponds and energy storage facilities are not relevant. The severity and scale of impacts by roads, substations and/or power lines and the solar field of PV developments were found to be higher generally than other power plant components during the construction stage. Components such as energy storage facilities, offices or on-site accommodation and temporary structures or scaffolding had the narrowest rating ranges (min = 1, max = 2; or min = 2, max = 3), indicating that the impacts from these components are fairly contained to the development footprint.

The ratings presented in Figure 3.8 were tested for significant difference between construction and operation. The power plant components for which a significant difference was found in ratings between the construction and operation stages are presented in Table 3.6. These results show little consistency between CSP and PV developments. The only commonality between the two technologies was a significant difference between the two development stages in the impact severity of temporary structures. Similar to the results for the biophysical components (Table 3.5), a significant difference was not found for the scale of impact by many power plant components. The full set of calculated p-values is presented in Appendix H. Further results specifically relevant to the construction and operational phases of solar power developments are included under Theme 2.3.

Table 3.6 The power plant components for which there was a significant difference in ratings between construction and operation. These are given for severity and physical scale for both CSP and PV. [A] With the exception of the Power block/inverter block, all the ratings were higher for construction than for operation. Significance levels provided in parentheses.

	CSP	**PV**
Severity	Waterworks (0.009) Temporary structures/scaffolding (0.019)	Roads (0.039) Solar field (0.002) Offices/On-site accommodation (<0.001) Temporary structures/scaffolding (0.001)
Physical scale	Power block/inverter block (0.028) Energy storage facilities (<0.001)	Temporary structures/scaffolding (0.039)

[A] Results from Mann-Whitney U test, n=15, p-level (alpha level) used = 0.05. Full results in Appendix H.

Theme 2: Feedback and experience with 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. Most responses to this section included suggestions for amendments to the EIA process and/or suggestions for minimising and managing impacts, which links to Theme 4 and is discussed in greater detail in Chapter 5.

Further to listing impacts related to solar power developments (as indicated in Theme 1), interviewees were asked whether they think EIAs sufficiently cover all impacts of a project on the biophysical environment; the majority of interviewees replied ‘yes’ (n=11), one interviewee was too unsure to answer and the rest replied ‘no’ (n=8). Three interviewees explicitly stated that all impacts are covered in detail. Some interviewees furthered their response with a comment; these comments were coded, and those mentioned more than once are summarised in Figure 3.9.

In addition to the majority of the interviewees agreeing that the EIA process sufficiently covers all impacts of solar power developments, two of the most common responses indicated in Figure 3.9 highlight EIA implementation as a greater concern. From these comments one can read that the aspects generally omitted in the EIA process are ‘cumulative impacts’ and ‘analysing topsoil and vegetation removal in depth’. Two specific examples of cumulative biophysical impacts mentioned as neglected were atmospheric pollution and insufficiently investigated resource requirements (e.g., water) prior to the start of a development. Although EIA implementation were shown to be a concern, further comments indicate that when properly implemented by competent EAPs and environmental consultancies, the EIA process is believed to be sufficient.

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 that might have been missed in the earlier projects’ EIAs are a matter of ‘learning as we go’.

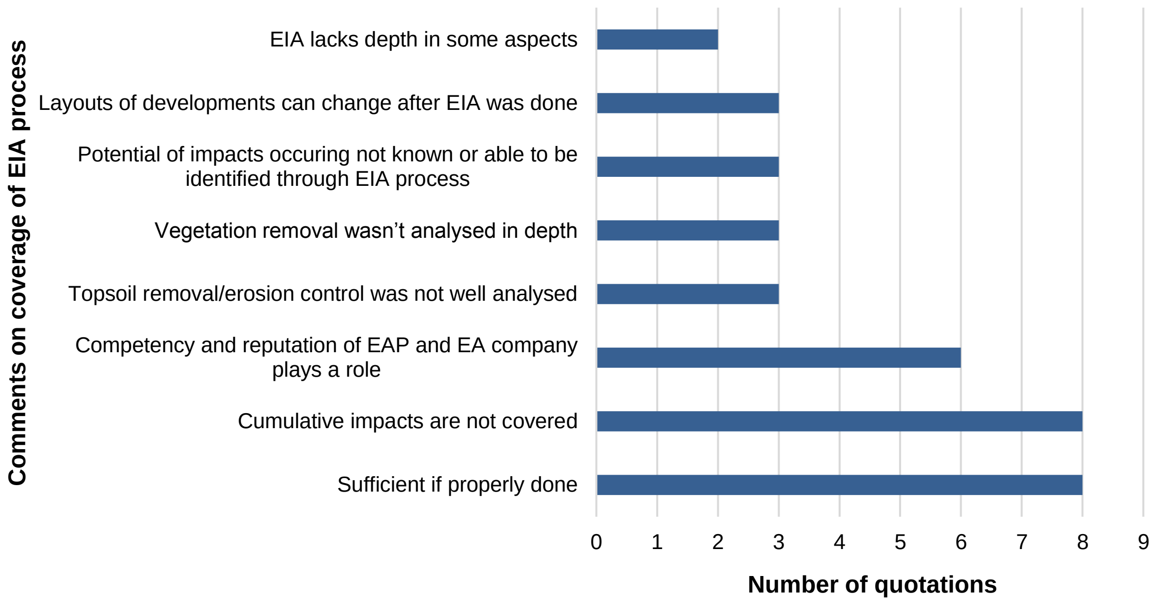


Figure 3.9 Summary of similar comments in response to the question of the sufficiency of the EIA process to capture all possible environmental impacts of a project.

Non-direct biophysical and socio-economic impacts that were mentioned frequently include recycling challenges, end-of-life challenges and life cycle impacts. In addition, the REIPPPP requirement stating that all renewable energy applications should have an EIA was questioned as this might not be the best approach. This requirement puts pressure on environmental consultants and EAPs who risk compromising the thoroughness with which EIAs are completed. Another EAP added that the 170-day time period given to complete the entire EIA process is very strict and does not always allow for needed refinements. The transition between the EIA report and the various other management activities and role-players was a sub-theme that enjoyed specific feedback in the interview process; this is elaborated on in Chapter 5.

Interviewees with prior practical experience of EIAs at solar power developments were invited to mention impacts they know are not covered sufficiently in the EIA process, specifically during the construction and operation phases. 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 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 DEA to intervene when there is suspicion that an EIA may have been insufficiently completed. Additional impacts mentioned more than once are summarised in Table 3.7.

It is believed these impacts are not included in the EIA process; as such they may pose an interesting challenge to ensuring their eventual inclusion in the EIA process, and their inclusion is likely to pose some interesting legislative and operational challenges. Some of these impacts (e.g., hindrance to animal movement and species attraction to the evaporation ponds) would require long-term monitoring during the EIA phase in order to identify the possibility of such impact on a specific location. The cumulative impacts during the operational stage were again mentioned.

Table 3.7 Impacts during the construction and operation stages mentioned by interviewees as being insufficiently covered throughout the EIA process.

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

During early stages of project planning and the EIA scoping phase, preliminary impacts of developments are identified based on spatial biodiversity datasets. The quality and representativeness of these datasets are relevant to minimising impacts on the underlying biodiversity at a specific location. Questions about the biodiversity datasets used for this purpose were included in the interview form. Interviewees were asked if they know what datasets are being used for baseline studies prior to solar power developments, to which 85% (n=17) replied 'yes' and 15% (n=3) replied 'no'. Not all of the interviewees, however, could refer to the correct dataset names. Frequently mentioned topics in the datasets included the following: vegetation, critical biodiversity, bird areas, bat areas, rivers and dams, wetlands, heritage resources, geology, conservation planning, solar resource data.

The South African National Biodiversity Institute (SANBI), the Department of Water Affairs and the DEA were the three data sources mentioned most frequently. Interviewees who knew which datasets are being used were asked if existing field survey archives, spatial datasets and maps were sufficient to predict the impact of solar power developments in South Africa. To this question 41% (n=7) replied 'yes' and 59% (n=10) replied 'no'. These responses were furthered by comments which are summarised in Table 3.8. An EAP from the CSIR confirmed that "*[m]uch of the information used in solar power EIAs have become generic, and these should be more pertinent and relevant to the development site*." In a related comment, an interviewee with experience as a specialist in EIA application suggested that a mandatory requirement to submit field data collected for EIA purposes to SANBI after a certain time period could aid in keeping national datasets updated.

Table 3.8 The most frequently given comments/suggestions to the sufficiency of datasets currently used to inform solar power developments (e.g., field survey archives, spatial datasets and maps).

Comment/Suggestion	Number of times recorded
Current datasets and maps have insufficient resolution and/or are outdated, especially in arid regions	14
Ground-truthing is necessary (verification of features represented in a spatial dataset with field investigation)	10
Outdated national datasets need to be updated, and the updated datasets should be used instead	6
A more strategic, tiered, systematic and cooperative approach is needed to keep datasets updated regularly	4
Existing datasets are sufficient to provide a good guideline to inform solar power developments	2
The SEA needs to be improved to better inform site selection for solar power developments	2
Site visits are needed to investigate seasonal variation of features represented in spatial datasets	2

Theme 3: Reference to SEA process

Throughout the interview process, mention was made of the SEA that was completed for wind and PV power. The feedback about the SEA process and the linkage to EIA's was limited to three specific observations:

1. A perception that the outcomes of the first wind and solar SEA are not utilised to guide EIAs.
2. A view that the usefulness of the SEA is limited given that the distribution of renewable energy projects are in reality constrained by the existing transmission grid infrastructure.

3. A suggestion that the SEA process must be improved and that CSP should be included in the new SEA being performed for PV and wind power.

Theme 4 and interview findings beyond study scope

The results under Theme 4 (Input regarding management and mitigation measures) are to a certain extent interlinked with the first three themes. All findings, however, indirectly and directly relate to management and mitigation of impacts, which are discussed in Chapter 5.

Throughout the interview process, interviewees were inclined to comment on both socio-economic impacts and indirect environmental impacts, which are not within the scope of the research objectives. For the sake of completeness, these responses were captured during the interview, but not analysed. A summary of these responses is included in Appendix I.

3.3.2. Site visit findings

The observations, conversations and photographs recorded during the field trip were combined to offer a collection of 'in-field' experience to support the results from the interview process. These findings largely correlate with what was found throughout the interviews, but site visits allowed for more specific insights regarding matters such as animal interactions and water impacts. With the exception of waste materials at sites still under construction and hydraulic fluid spills at Khi Solar One (Site 5), no unexpected adverse environmental impacts were observed during the site visits. Key findings from the site visits are summarised in Table 3.9. Photographs of specific phenomena observed at different sites are presented in Figure 3.10 to accompany the findings summarised in Table 3.9. Comprehensive field notes are included in Appendix J under the different biophysical categories and for each site.

Table 3.9 Selected key findings from the site visits per impact category. Findings are arranged as associated with either construction or operational activities. Full site visit notes and findings out of the study scope are included in Appendix J.

<table>
<tr><th>Impact category</th><th>Observations and findings related to construction activities</th><th>Observations and findings related to operational activities</th></tr>
<tr><td rowspan="2">Impacts on fauna</td><td colspan="2">• All sites were different in the way animal movement into and out of the development footprint is allowed or managed (see Figure 3.14 A).
• Steenbok (Raphicerus campestris), rodents and snakes like Puff adders (Bitis arietans) were said to be common occurrences within development footprints.</td></tr>
<tr><td>• Birds nesting in power plant infrastructure was recorded at Sites 1-4 (see Figure 3.14 B)
• A Striped polecat with rabies had been found near the temporary buildings of Site 4</td><td>• Rodents and Aardvark (Orycteropus afer) were said to gnaw on cables and wires at Sites 1 and 2.
• Birds have been observed in flight (e.g., Falcons, Eagles, Flamingoes) and nesting (Black-winged stilts) around and in the evaporation ponds of Sites 5 & 6 (see Figure 3.14 C).
• Three flux-related bird fatalities had been recorded at Site 5 (central receiver facility)
• Two mammal drownings had occurred at site 6 (Bat-eared fox and an Aardwolf)</td></tr>
<tr><td>Impacts on flora</td><td>• Vegetation was removed in the solar fields of Sites 1, 5 and 6 but kept intact at the other sites.
• At Site 4, two green areas were established for the relocation of six Kraal aloes (Aloe claviflora, see Figure 3.14 D).</td><td>• Where natural vegetation was kept intact, it is seen as an effective natural dust suppressor.
• At Site 2, the vegetation was kept intact and the development footprint was also still used for sheep grazing by the landowner.
• Vegetation regrowth is generally encouraged at all visited sites, except for Site 6 where vegetation in the solar field is a fire hazard.
• Alien species such as Mexican poppies (Argemone Mexicana) and Prosopis juliflora were recorded at Sites 3 and 5 respectively</td></tr>
<tr><td>Soil/geological impacts</td><td>• Topsoil clearance has occurred in the solar fields of Sites 1, 5 and 6 but is rehabilitated at an embankment (see Figure 3.14 E).
• Soil is impacted at all sites by the construction or installation of pylons, trenches and roads.</td><td>• The entire solar field at Site 6 needed to be levelled on different terraces and the soil compacted (see Figure 3.14 F).
• Depending on the storm water management plan, erosion was a problem at some of the sites.</td></tr>
<tr><td rowspan="2">Impacts on water</td><td colspan="2">• The storm water management plans were problematic at all sites and required revision</td></tr>
<tr><td>• Water is predominantly used for dust suppression during construction.</td><td>• No standard practice was found regarding the regularity of PV panel washing. This ranged from once every six weeks to twice a year. Borehole water is used at Sites 1, 2 and 3, and the treatment varies between sites. No quantities were given for this activity.
• Sites 5 and 6 have annual water use permits of 300 000 m^3 and 400 000 m^3 respectively.</td></tr>
<tr><td>Aerial/audial</td><td>• Dust and noise were the only recorded aerial or audial impacts.
• During construction of Site 5, complaints were apparently received about the excessive dust at a small community 5 km away.</td><td>• Dust during strong winds was found to be problematic at sites where vegetation and topsoil were removed. Eventual regrowth in the solar field assisted in this regard.</td></tr>
<tr><td>Spills and waste</td><td>• Concrete spills were noticed at Site 4.
• Excessive waste (e.g., plastic, pallets and broken panels) and spills were recorded in the construction camp of Site 3 even though this area was supposed to be rehabilitated already.</td><td>• Oil- or hydraulic fluid spills are recorded to have occurred at four of the six visited sites. The containment and treatment of these vary per site.
• Lessons were learnt at Site 6 regarding salt spillage and leakage of the heat transfer fluid at the neighbouring Kaxu Parabolic trough plant.</td></tr>
</table>

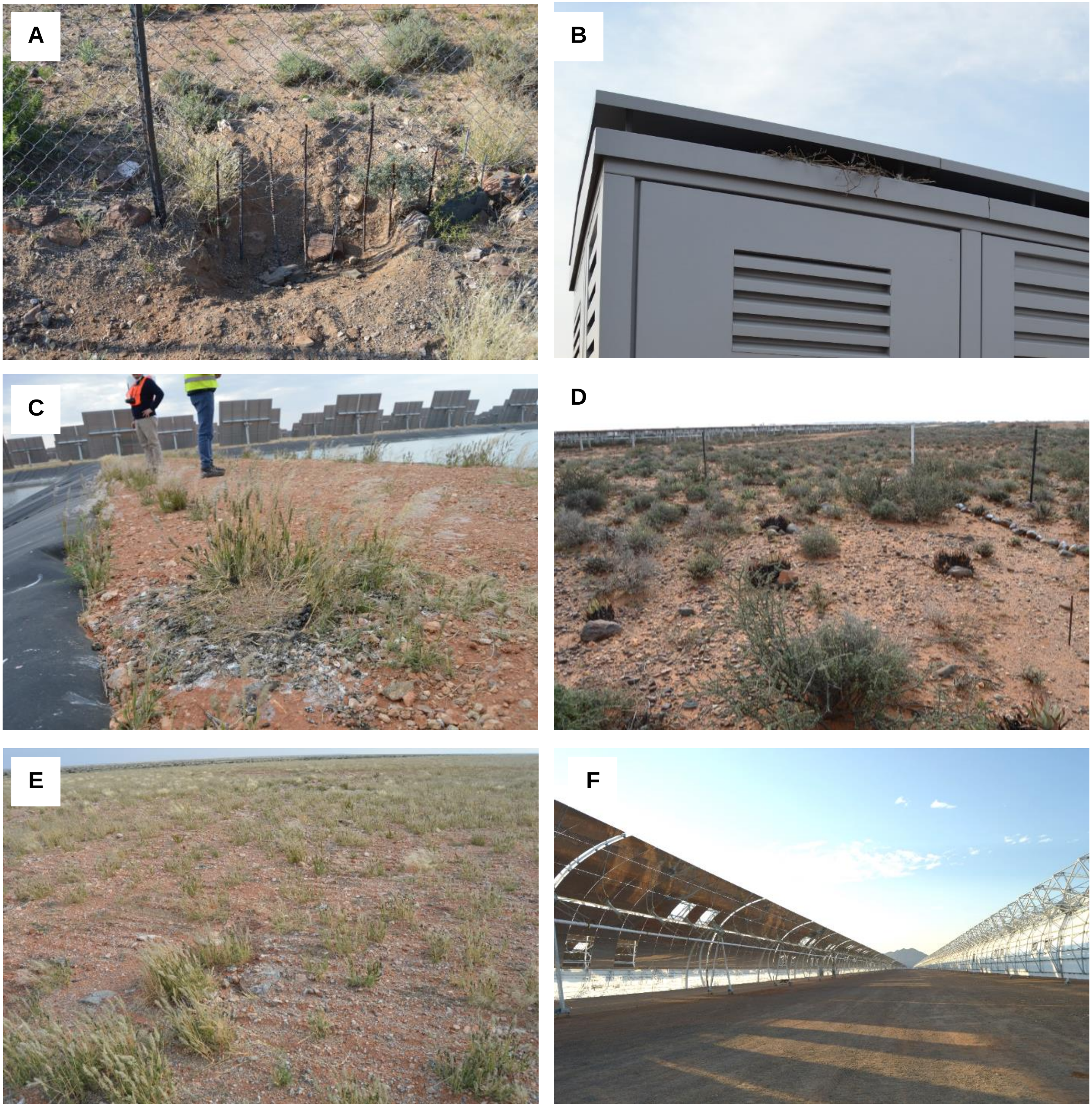


Figure 3.10 A – An example of how animals burrow underneath the development fence and an improvised attempt to keep them out at Site 3; B - A nest in a small opening at the top of a transformer building at Site 4; C – An empty nest at the edge of an evaporation pond at Site 5. Some of the heliostats of the solar field are visible in the background; D - One of the 'green areas' at Site 4 where six Kraal Aloes were relocated from the solar field prior to construction; E - The topsoil embankment at Site 5 during the early stages of rehabilitation; F - A row of parabolic troughs at Site 6 showing the cleared and compacted ground of the solar field. Photo credit for A-F: Justine Rudman

3.3.3. Spatial analysis

The development footprints of all solar power plants were extracted from the renewable energy EIA applications database for all projects up to the third round of the REIPPPP. Power plants with approved EIA applications were differentiated from power plants selected as preferred bidders of the REIPPPP. The number of projects with approved EIA applications is higher than the number of preferred bidders and comprises a larger surface area than that of the preferred bidders. Not all of these projects enter into construction, but this dataset highlights how many EIAs receive approval in the study area. The preferred bidders make up a limited number of projects. These have been committed for construction and operation and thus contribute to the cumulative direct environmental impacts. This subset of spatial data for solar power developments (all of which are approved solar power EIAs and preferred bidders) was used to quantify the cumulative affected area in the different biomes and bioregions as well as on the different vegetation types as per the National Vegetation Map of 2012. South African Protected Areas, National Protected Areas Expansion Strategy focus areas, Important Bird Areas and Strategic Water Source Areas were also analysed for enclosure of or proximity to solar power development areas.

Impacts on biomes

Table 3.10 summarises the total area per biome (in km^2) for which a) solar power EIA applications have been approved and b) projects have been assigned to preferred bidders throughout the first three rounds of the REIPPPP. At the time of writing, projects have been approved for round 3.5 and round 4 of the REIPPPP, but the EIA data of these projects were not included in the latest datasets made available by the DEA. Here it was confirmed that the Nama-Karoo and Savanna biomes have a clear majority proportion of affected area (70.32% and 22.85% respectively) from all preferred bidders' projects. When looking at the total approved EIA areas per biome, one sees a slightly more spread out distribution across the biomes with about 10.9% of the power plant area located in the Grassland Biome.

Table 3.10 The area per biome for which solar power EIA applications have been approved and the total area of projects which were preferred bidders throughout the first three rounds of the REIPPPP; figures rounded to one significant digit.

Biome	Total area* of approved EIA applications per biome (km^2)	Percentage of the total area* with approved EIAs per biome	Total area with approved EIA application for preferred bidders** (km^2)	Percentage of total area for preferred bidders**
Nama-Karoo Biome	4455.0	49.3%	702.0	70.3%
Savanna Biome	2854.1	31.6%	228.2	22.9%
Grassland Biome	988.9	10.9%	16.7	1.7%
Fynbos Biome	257.0	2.8%	30.4	3.0%
Succulent Karoo Biome	234.4	2.6%	5.1	0.5%
Azonal Vegetation	176.4	1.9%	10.6	1.1%
Albany Thicket Biome	68.4	0.8%	-	-
Desert Biome	5.4	0.1%	5.4	0.5%
Indian Ocean Coastal Belt	0.9	0.01%	-	-
Total	**9040.4**	**100%**	**998.4**	**100%**

*Total area for all approved solar power developments throughout rounds 1 – 3 of the REIPPPP. Not all these projects continue on toward construction and operation.

**A subset and smaller area than that of all approved EIAs.

Footprint impact on vegetation type and bioregions

Table 3.11 summarises the areas for the ten vegetation types within the Nama-Karoo and Savanna biomes affected most by footprints caused by solar power development. The five most affected vegetation types by development footprints of preferred bidders in descending order were Bushmanland Arid Grassland, Northern Upper Karoo, Kalahari Karroid Shrubland, Bushmanland Basin Shrubland and the Gordonia Duneveld. The Bushmanland Arid Grassland and the Eastern Upper Karoo are the most 'targeted' vegetation types for solar power development, representing 26% and 15% of the preferred bidders' area respectively. However, both have a conservation status of 'Least threatened'.

Table 3.11 The 10 most impacted vegetation types (Mucina & Rutherford 2006) by approved solar power EIA applications and projects, which were preferred bidders throughout the first three rounds of the REIPPPP. Vegetation types are primarily grouped according to the associated bioregions and secondarily from large to small for total area of approved EIA applications for preferred bidders; figures rounded to one significant digit.

Vegetation type	Total area of all approved solar power project EIA applications (km^2)	Total area of approved EIA applications for preferred bidders only (km^2)	Associated bioregion (Nama-Karoo = NK, Savanna = S)
Bushmanland Arid Grassland	1159.5	256.3	Bushmanland bioregion (NK)
Kalahari Karroid Shrubland	529.4	128.3	Bushmanland bioregion (NK)
Bushmanland Basin Shrubland	1161.5	116.4	Bushmanland bioregion (NK)
Lower Gariep Broken Veld	87.6	14.5	Bushmanland bioregion (NK)
Northern Upper Karoo	643.3	153.9	Upper Karoo Bioregion (NK)
Eastern Upper Karoo	430.3	19.7	Upper Karoo Bioregion (NK)
Gordonia Duneveld	675.0	93.5	Kalahari Duneveld Bioregion (S)
Kimberley Thornveld	489.7	39.9	Eastern Kalahari Bushveld Bioregion (S)
Olifantshoek Plains Thornveld	211.8	37.7	Eastern Kalahari Bushveld Bioregion (S)
Kathu Bushveld	152.2	34.4	Eastern Kalahari Bushveld Bioregion (S)

Impact on protected areas, important biodiversity areas and areas of significant natural resources

The solar power EIA applications dataset was analysed using the South African Protected Area Database (DEA 2016a) to identify and calculate any potential overlap of solar power development with the conservation estate. It was found that a number of approved EIA applications for PV projects (8.5% of approved solar power applications) are located within protected areas such as nature reserves, national parks, biosphere reserves and world heritage sites located in the Nama-Karoo or Savanna. Only three of these projects were chosen as preferred bidders, and all three are located in biosphere reserves: one in Limpopo province and two in North-West province. No CSP projects are located within protected areas.

Of the remaining approved solar EIA applications, 17.5% are within 0-10 km of a protected area, and the rest are located within 11-290 km of a protected area.

The likelihood that new developments are located in already-existing protected areas was assumed to be less than in areas not-yet protected, although areas of ecological significance have already been earmarked through the National Protected Area Expansion Strategy (NPAES) last updated in 2010 (SANParks 2010). To determine how much of the development area falls within these NPAES focus areas, the development locations along with solar power EIA areas were analysed using the intersect tool in ArcGIS. NPAES areas were allocated and identified by South African National Parks as intact and unfragmented areas of high importance for ecological persistence and biodiversity representation and suitable for the creation or expansion of large protected areas (SANParks 2010). It was found that the only areas that overlapped with NPAES focus areas were those with approved EIA applications for PV developments. None of these projects, however, were chosen as preferred bidders throughout the first three rounds of the REIPPPP. The specific NPAES focus areas subject to approved EIAs for PV developments are Bhisho Kei, Kamiesberg Bushmanland Augrabies, Moist Escarpment Grasslands and Gariep. Protected areas, NPAES areas, Important Bird Areas, Renewable Energy Development Zones (REDZ) for PV power and approved solar power EIA application areas located within the Nama-Karoo and Savanna biomes are all shown in Figure 3.11.

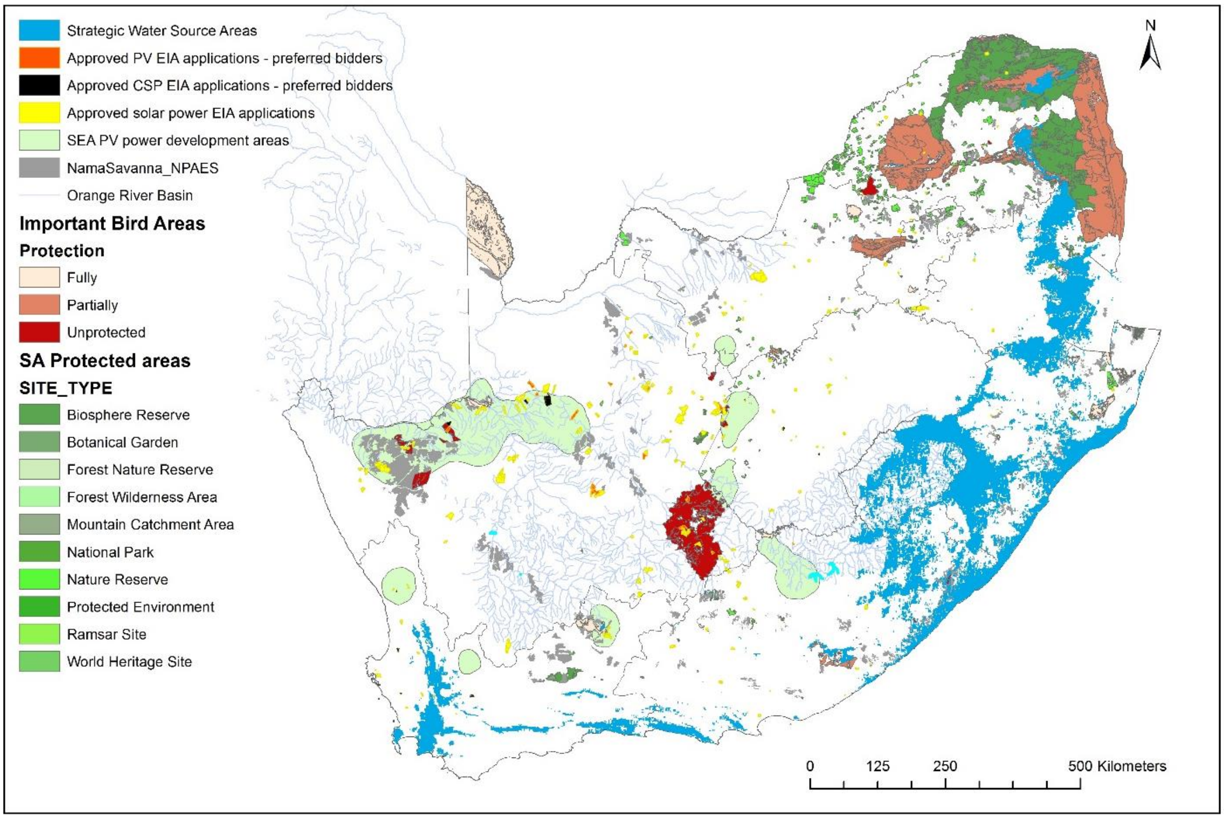


Figure 3.11 A map of South Africa showing national Strategic Water Source Areas and PV power Renewable Energy Development Zones. Areas with approved solar power EIA applications and the following protected or sensitive biodiversity areas are shown for the Nama-Karoo and Savanna Biomes only: Important Bird Areas, SA Protected Areas and National Protected Areas Expansion Strategy focus areas.

Important Bird Areas (IBAs), as determined by BirdLife South Africa (BirdLife South Africa 2015) are classified as 'Unprotected', 'Partially protected' or 'Fully protected'. A subset of the IBAs was created by extracting those IBAs which are located within the Nama-Karoo and Savanna Biomes. This subset was then analysed to determine what proportion of these areas have approved solar EIA applications and preferred bidders' developments located within them. The sizes of these areas are summarised in Table 3.12. The specific unprotected IBAs which were identified as being affected by PV preferred bidders' developments in the Northern Cape are the Platberg-Karoo Conservancy, Mattheus-Gat Conservation Area and in the North-Western Province, the partially protected Magaliesberg IBA. The unprotected IBA, Mattheus-Gat Conservation area, was identified as being affected by CSP developments of preferred bidders.

In general, Table 3.12 shows that those developments located within unprotected IBAs are mostly for PV. The area of solar power development within partially protected IBAs was found to be very low (0.2 km^2) and zero in fully protected IBAs.

Table 3.12 Areas within Important Bird Areas: the area sizes for which solar power EIA applications have been approved and area sizes that were selected as preferred bidders throughout the first three rounds of the REIPPPP.

Protection status	**Total area of all approved EIA applications, non-preferred bidders included within IBA (km^2)**			**Total area of approved EIA applications for preferred bidders within IBA (km^2)**		
	CSP	PV	Total	CSP	PV	Total
Unprotected	17.7	534.9	552.6	7.6	168.8	176.5
Partially		12.5	12.5		0.2	0.2
Fully		19.8	19.8			

In addition to the solar power development enclosure within IBAs, the proximity was calculated for approved EIA applications and preferred bidders, which are not located within an IBA. For all approved EIAs and preferred bidders combined, it was found that only about 8% of solar power developments are within 5 km of an IBA. Most solar power developments (approximately 88%) were found to be more than 10 km away from any IBA. The full set of these results is included in Appendix K.

Analysis using the ArcGIS intersect tool was done to determine if any approved EIA areas for CSP developments are located within strategic water source areas. Results showed that the location of these developments and these water source areas do not spatially overlap. The strategic water source areas are indicated in Figure 3.11.

Lastly, the areas identified with top PV development potential throughout the National SEA for wind and PV power as REDZ (CSIR 2013) were analysed to determine how many approved EIA applications and preferred bidders' developments are located within these areas. Of the approved EIA applications for PV, 17% were located within the PV REDZ and 8% of these projects were selected as preferred bidders. Of the total preferred bidders' for PV developments, only 15% were located in a PV REDZ. The co-location of these areas with that of approved solar power EIA applications can be seen in Figure 3.11.

Possible future distribution and footprint impact at increased capacity allocations

Current allocated solar power projects represent approximately 19% and 18% of the capacity allocated to PV and CSP in the IRP Update respectively (DOE 2013). Possible areas to be transformed in the future can be calculated using a simple assumption that the remaining 81% for PV and 82% for CSP will be located in similar and adjacent solar resource areas. Their footprints can be extrapolated to similar biophysical areas; that is, the variation of proportional distribution of projects within biomes may be minimised as indicated in Table 3.10. The limitations in this simple assumption include unknown timing of when area would be transformed, the unknown extent of transmission grid expansion and the assumption of consistent land use efficiency for both CSP and PV projects. This extrapolation revealed that potential future areas per biome under solar power development will likely be relatively low. The expected transformed footprint by 2030 was calculated at approximately 1.57% in the Nama-Karoo and 0.31% in the Savanna biome. The full set of results for the expected future affected area per biome is included in Appendix K.

3.4. Discussion

Studies of public perception and attitudes towards renewable energy technologies can be found in the literature (e.g., Ek 2005; Tsantopoulos et al. 2014; Karlstrom & Ryghaug 2014), but experience of these technologies from professionals in the field is not as easy to find. Spatial analysis has been used for questions related to land use efficiency of solar power developments (Hernandez et al. 2014; Hernandez et al. 2015), but little work exists apart from the work of Fluri (2009) and the guidance provided through the identification of REDZ in the SEA completed for wind and PV power (CSIR 2013). This study provides an attempt at understanding the direct impacts of South African solar power developments. A few international studies (e.g., McCrary et al. 1986; Kagan et al. 2014) provide some background, but other than a planned avifaunal monitoring programme at Khi Solar One and an MSc thesis by Visser (2016) which focussed on the impacts of one PV facility on birds, no research-based data or publications are available reflecting biophysical impacts of solar power developments locally.

3.4.1. Synthesis of findings

The most recorded responses from the interviews regarding the various impact categories, such as impact on avifauna and water consumption, are similar to the findings presented in a recent review paper by Hernandez et al. (2014) and a more detailed earlier overview presented by Tsoutsos et al. (2005). Numerical ratings further supported the findings from the content analysis (e.g., high relative high median rating for the impact severity on birdlife and water usage during operation by CSP developments). Impacts similar to those assessed by Turney and Fthenakis (2011) such as impacts to wildlife, wildlife habitat and geohydrological resources were also recorded. Due to the widely acknowledged reality of these impacts, it arguably provides an opportunity for context-specific description and management guidelines of these impacts within an ecological context of a development.

No overlap was found with the location of solar power developments and that of Strategic Water Source Areas. However, the concern for the impact of CSP on water resource availability together with the comment that cumulative impacts are not covered sufficiently in the EIA process highlights the need for strategic planning of water resource allocation to CSP. This is specifically relevant around the Orange River Basin where water supply is known to be limited (DWAF 2004); strategic planning of this kind is in accordance with the term at which power purchase agreements are signed with developers. Early acknowledgement of a possible risk provides a starting point for proper description and management of this kind of impacts resulting from CSP developments around the vicinity of the Orange River. Further inquiries could focus around how water extracted from the river affects ecosystems and livelihoods downstream.

The findings from the site visits on adverse impacts coincided with that of the interviews with the added value in being able to observe such impacts on-the-ground. Although out of scope of this study, the positive attitudes and practice at some sites was an unexpected, pleasant finding. As also found in theme 1 of the interview results, dust impact associated with vegetation and topsoil removal in the solar field was regarded as a major impact within the immediate environment of a solar power plant. Impacts associated with fauna, flora and water mostly appeared to be well planned-for during the EIA phase, and when unanticipated impacts occurred – such as the nesting of birds in structures or buildings and the attraction of species to evaporation ponds – impromptu actions were implemented. These observations correlate with feedback to the coverage of the EIA process where it was highlighted that the attraction of species to development footprints is not sufficiently covered in the EIA process. This confirms the 'mega-trap' concept described by Kagan et al. (2014) where solar power developments act as an ecological-trap due to the creation of favourable areas offering reproductive and foraging advances within the surrounding ecosystem (Dwernychuk & Boag 1972).

Exploring the impacts on fauna and habitat transformation in general combined with the feedback regarding the quality of biodiversity datasets used in the early stages of the EIA process justifies a clear concern, but it also creates a timeous opportunity. The timing in South Africa is ideal considering renewable energy developments are still in the early stages and there is a high potential to gain experience about these impacts. This opportunity is to focus on mapping the biodiversity, including specialist studies in planned development areas and developing best-practice guidelines that can proactively avoid impacts on species diversity as well as take into account seasonal migration of avifauna. Thus the suggestion from interviewees that there be a strategic, cooperative approach to keeping these data updated is a relevant one. Furthermore, there may be significant potential to update datasets using the in-field data, which gets collected as part of the EIA process.

In addition to ensuring the use of representative datasets to avoid impacts, results regarding the identified direct impacts would be best supported with species-specific monitoring data to determine what the impact on avifauna is from solar power development. However, no such data were in existence at the time of writing. This absence of data was confirmed by Samantha Ralston-Paton, a Birds and Renewable Energy Manager at BirdLife SA, who participated in the interview process and was referred to by other interviewees as the current 'key contact' regarding birds and renewable energy in South Africa. Such monitoring data would support the impacts previously mentioned that are specific to CSP and PV, of which 'Impacts on avifauna by CSP towers' and 'Collison impact by PV panels or heliostats' were the most popular; these impacts are reflected in international studies as well (McCrary et al. 1986; Kagan et al. 2014; Lovich & Ennen 2011a). No proof, however, is available for any of these impacts as peer-reviewed studies based on South African data. A Master's study by Visser (2016) investigates what the impact of avifauna is at a PV facility close to Postmasburg in the Northern Cape, but it yielded no evidence for concern regarding the link between bird mortality and PV panels. An avian monitoring programme planned to start at Khi Solar One is the only known monitoring programme of its kind at the time of writing. Ideally, data gathered from programmes like these should be used to inform management and mitigations measures and regulations as have been developed by BirdLife South Africa (Smith 2015). This data in turn could inform the establishment and information available for IBAs (BirdLife SA 2015).

The combined findings from the interviews and site visits made it clear that during the construction phase of solar power development is when most of the direct impacts are the severest and most spatially concentrated. These impacts are believed to be similar to conventional construction-related impacts (Tsoutsos et al. 2005). However, key impacts such as that on fauna through roadkill and solar flux, glint and glare, and the water consumption of CSP developments have been identified as being notable impacts experienced throughout operation as well. In addition to the localised interactions and experiences with animals on site, the off-site impacts such as roadkill are harder to monitor and offer an important area of study to understand the complete impact of such developments on the surrounding environment and ecosystem (Coffin 2007). This phenomenon could be described as 'a lollipop effect', a term conceived during this study in recognition of the significance in the findings that impacts extend well beyond the development footprint (the edible part of the lollipop) to its peripheral, supporting infrastructure footprint (the stick of the lollipop).

A notable positive site-visit observation was seeing the co-use of land. It is understandable that not all developers would want to have the liability of livestock in the development footprint. But this approach could certainly be explored, given the beneficial consequence of not only dual land use, which avoids the disturbance of additional habitat, but the land-owner can continue to farm the land while the developer benefits from ongoing vegetation control.

During the site visits it was energizing to witness positive attitudes and initiatives regarding adaptive management and the transfer of lessons-learnt from previous power plants. This serves as evidence toward some progress made in the EIA process where problematic transitions have been recorded between EIAs, environmental management programmes and environmental management systems (DEAT 2004). Again, the site visit findings confirmed what was voiced at an administrative level by interviewees from the DEA and Eskom about 'learning-on-the-go'. All findings considered, and with special reference to the interview feedback regarding the EIA process, a key outcome remains that the current EIA process is sufficient, but the implementation thereof followed by the management of impacts are exceptionally important. Further matters related hereto are discussed in Chapter 5.

3.4.2. Landscape outlook

Forming part of the rationale for this study, the various environmental impacts associated with a single solar power development might be insignificant, but the landscape-wide accumulation of impacts is possibly of concern. Energy systems are geographically distributed, but certain components of these systems are embedded at specific geographical locations (e.g., power plants and transmission infrastructure), which form 'geographies of connection, dependency and control'. Moving from conventional to renewable energy resources also is regarded intrinsically as a geographical process (Bridge et al. 2013).

The findings from the interviews and site visits identified a spectrum of impacts that occur at the solar power plant level; the spatial analysis assisted in investigating the distribution of these impacts across the Nama-Karoo and Savanna biomes. All three of these data collection techniques and the findings of impacts on fauna, biodiversity and ecology, and landscape transformation link back to the importance of appropriate siting and mapping. The extreme importance of representative biodiversity data should thus be heavily stressed (Reyers et al. 2007; Mace et al. 2012). Missing data risks putting in danger individuals and/or populations of species in ecosystems with limited geographical distributions as well as affecting the alpha diversity. A repetition of missing spatial biodiversity data could then lead to impacting beta diversity (Schmitz 2007).

An area that arguably was weakly investigated in this thesis is the aforementioned 'geographies of connection', which has the potential to result in widespread habitat transformation. However, including analysis of the expansion of power lines and access roads from spatial data, in combination with real incident-data, would give further insight to the expected ecosystem-level landscape-scale impacts of supporting transport and access infrastructure associated with solar power plants (Andrews 1990; Hernandez et al. 2015). Lastly, it should be noted that the assessment of impacts associated with solar power support infrastructure poses an additional challenge in identifying the relevant infrastructure since existing infrastructure (e.g., substations and transmission lines) might be used for a new development or would need to be re-established (Kruger & Jodas 2010).

The motivation behind the SEA is good in that it aims to identify areas as REDZ where environmental impacts are minimised. Given that the SEA is based on national and local biodiversity datasets (CSIR 2013), maintaining updated datasets is very important to guide proper location of solar power plants. Thus, if the location of new power plants is within SEA-identified REDZ, one should be confident that significant adverse cumulative landscape impacts are unlikely to occur from the collective location of these power plants. In addition, in contrast to EIAs, which are a legislative requirement, the findings of a SEA are not enforceable and are primarily used to guide development. According to Therivel (2012), the ultimate aim of a SEA is "*to help protect the environment and promote sustainability*". However, taking into account that only 15% of PV projects are located within the REDZ along with the three points of feedback on SEA throws into question the effectiveness 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 the matter.

The total proportion of affected area in the Nama-Karoo and Savanna biomes under current REIPPPP projects is relatively low and was found to remain low even under a four-fold increase of solar generation capacity. Guided by the solar power capacity allocation in the IRP Update, an approximated combined area representing 1.88% of the Nama-Karoo and Savanna biomes is expected to be under solar power development by 2030, according to known projections. This projected footprint impact, together with assumed sensible siting of solar power development, highlights how an understanding of direct impacts on ecological components can decrease and contain risks of indirect impacts as well as reduce disturbing equilibriums within systems across the landscape (Ingegnoli 2002; Schmitz 2007). However, the assumptions that were used for this analysis include many unknowns, and significant refinement would be needed for a more reliable estimate.

Across the study area, and at a landscape-scale, habitat transformation and fragmentation resulting in land use changes potentially impacts the affected ecosystems in providing ecosystem services (Reyers et al. 2009). There is thus a case for considering the trade-offs of renewable energy resources as a provisioning ecosystem service compared to the impact of such developments on other supporting ecosystem services, e.g., the impact of topsoil removal from solar power development on flood regulation.

3.5. Conclusion

The various data collection and analysis methods used appear to have resulted in findings that achieve the objective of this chapter. A comprehensive investigation and synthesis of the initial utility-scale developments provides an initial indication of the direct environmental impact of solar power developments in the two arid biomes.

The findings suggest that there is a general understanding of the direct environmental impacts amongst experienced and professional individuals in the field and that the EIA process as governed by NEMA (Act no. 107 of 1998) is sufficient if properly executed by a competent EAP. Direct environmental impacts can be expected at both the construction and operation stages of solar power development. However, impacts during the construction stage of solar power developments are perceived to be higher than that of the operational stage. Monitoring data at solar power plants would be complementary to the preliminary results presented here, and landscape-wide, integrated strategic planning to address cumulative impacts would proactively address future crises with regards to water supply for solar power generation.

CHAPTER 4: THE IMPACTS OF SHALE GAS PRODUCTION

Shale gas could play a significant role in the diversification of the future energy system. If the shale gas resource is economically viable and developments proceed, it could introduce a range of impacts and challenges to the arid environment falling within the exploration right areas. The uncertainty around the planned development, the associated timeline and expected impacts is ongoing. However, pre-emptive enquiry into shale gas development from various interest groups in South Africa puts the country generally in an ideal position in terms of readiness. A concise investigation into the prospective regional adverse environmental impacts associated with shale gas development is presented.

4.1. Introduction

4.1.1. Status of shale gas development in South Africa

Internationally, natural gas increasingly is considered a valuable fossil fuel as a lower carbon-intensive energy alternative. Its flexibility for use in electricity generation, space heating and transportation contributes to its increasing value (Melikoglu 2014), and it represented approximately 24% of the global total energy supply in 2014 (BP 2015). Included in the draft National Development Plan of 2012, shale gas is being considered as an energy source to contribute to the diversification of the South African energy system; this follows the lifting of a moratorium, which has hindered exploration of this resource (Department of Energy 2013a). Natural gas generates about half the carbon emissions of coal per useful output and is thus generally considered as bridge fuel to replace coal and supplement renewable sources such as wind and solar energy in a low-carbon economy (Nature 2009). The greenhouse gas emissions footprint of shale gas has been found to be higher than that of conventional gas (Howarth et al. 2011); arguably, this motivates for the emission-intensity of shale gas to be assessed separately.

Shale gas production in South Africa is a contentious matter with two generally distinct interest groups: those who see too large a risk in potential environmental degradation and health impacts in Karoo communities (e.g., Ferrar et al. 2013) and those who accentuate the link between increased energy security and economic prosperity (De Wit 2011; Warren 2013). These concerns represent generally valid points of view in the pursuit of sustainable development, and similar issues have always been part of the complex interaction between energy generation and the environment (Dincer & Rosen 2013).

Oil exploration by the then SOEKOR (now PetroSA) occurred between the mid-1960s and 1979, but it was abandoned after finding no promising oil resources (De Wit 2011). Venting natural gas was observed in some inland areas but was not considered of commercial significance. Following the success in the Barnett Shale in the U.S. in the late 1990s, attention was turned towards the shale gas resources of the rest of the world, including South Africa (Mills et al. 2012). Interest in the Karoo Basin then resurfaced through an ultimately failed exploration right application in 2008 by Bundu Oil and Gas (Cropley 2013). The moratorium on shale gas exploration was imposed in 2011 but then lifted in September 2012 (Warren 2013). Currently, Shell, Falcon- and Bundu Oil and Gas have applied for exploration rights covering 171 811 km^2 of the central Karoo region (PASA 2013). No shale gas exploration rights have been granted as of the time of writing (October 2016).

4.1.2. The Karoo Basin

In earlier years, exploration of the 'Karoo' was intended to refer to the 'Karoo Basin' as a geological unit, but this was misunderstood by some stakeholders as referring to the Karoo region. To clarify, the geographic distribution of the Karoo Basin is approximately 700 000 km^2 in size and extends across more than half of the country (Mills et al. 2012; PASA 2013), and although overlapping towards the south, it also extends the Karoo region (Ingle & Atkinson 2015). A map of the Karoo Basin is included as Appendix L.

The Prince Albert, Whitehill and Collingham formations, belonging to the Permian-age Ecca shale group, are the formations believed to hold the majority of shale gas in the Karoo Basin. A suggested total of 485 trillion cubic feet (Tcf) of technically recoverable shale gas in the Karoo Basin was reported in 2011 (Kuuskraa et al. 2011), but two years later the same authors adjusted this amount to 390 Tcf (Kuuskraa et al. 2013). This recalculation of the initial estimates of Kuuskraa et al. (2011) by the Petroleum Agency of South Africa (PASA) suggests that technically recoverable gas-in-place can be in the range of 30-500 Tcf (Decker & Marot 2012). No exploration has been done in the Karoo Basin as of November 2016, and the size of the resource is thus not yet determined. A comprehensive description of the Karoo Basin and findings from the first deep boreholes has been given in Chapter 2.

Despite the uncertainty of the economically viable resource size, several nationally coordinated prospecting and impact related studies have been undertaken throughout the five years in preparation and anticipation of the reality of shale gas development in South Africa. These studies date back to 2012 and were undertaken by different entities. The entities include the Water Research Commission (Steyl et al. 2012; Esterhuyse et al. 2014), a Working Group coordinated by PASA (Mills et al. 2012), a Centre of the Department of Science and Technology (CIMERA 2014), a research Group at Nelson Mandela Metropolitan University (NMMU 2014) and the Department of Environmental Affairs (DEA) (Council for Scientific and Industrial Research 2016a). The objectives of these studies include addressing specific geology or geohydrology-related issues (Steyl et al. 2012), exploring the characteristics of the Karoo Basin, establishing a baseline and strategically assessing the impacts of shale gas development (Council for Scientific and Industrial Research 2016a). A summary of the descriptive information for the abovementioned studies is provided in Appendix M. In addition to these studies, there have been independent studies for other commercial and non-profit entities; for example, the Karoo Groundwater Atlas for Shell (Van Tonder 2012) and a study by the World Wildlife Fund South Africa on the water-related impacts of shale gas operations (Bole-Rentel 2015).

The Strategic Environmental Assessment for Shale Gas Development (SEASGD) is the process for assessing all social, economic and environmental impacts related to shale gas development according to four different scenarios. The process involves input from the most diverse group of stakeholders in South Africa. Amongst the other studies listed in Appendix M, the SEASGD process, governance and progress are readily available to the public, and interested and affected parties are invited to comment on draft chapters of this report and participate in stakeholder meetings. As mandated by the South African cabinet, the DEA is responsible for this assessment and initiation thereof. The SEASGD was officially launched in May 2015 by the Departments of Environmental Affairs, Science and Technology, Mineral Resources, Energy, and Water and Sanitation. The final SEASGD report was published in November 2016 (Scholes et al. 2016).

The results from selected chapters of the SEASGD, the initial results of the Karoo Research Initiative (KARIN) project and results from several postgraduate students at the Africa Earth Observatory Network were the most current sources of information on the status of shale gas development in the Karoo Basin as of November 2016.

4.1.3. Chapter objective

The objective of this chapter was to investigate what the prospective direct environmental impacts of shale gas development are in the Karoo Basin in the context of the Nama-Karoo biome as the most affected biome. This objective was explored by an attempt to understand the prospective impacts by using existing local knowledge in combination with international records of reported experiences with shale gas development. The intention was to keep this investigation as focussed as possible by considering the assumption that an economically viable resource size of, for example, 20 Tcf (*i.e.*, the threshold for the 'Big Gas' scenario of the SEASGD) or more exists and will be exploited as the sole future scenario for shale gas development in South Africa.

International lessons and knowledge of the impacts of shale gas development play an important role in the projection of expected impacts if shale gas development commences in the Karoo Basin. For this reason, in addition to that already given in Chapter 2, section 4.2 provides a concise overview of such impacts as well as the findings of the SEASGD, the most current South African study on the subject matter. A description of the method which was used follows section 4.2.

4.2. Overview of the environmental impacts associated with shale gas development

4.2.1. Lessons from international experience

Having had no practical experience with shale gas development in South Africa, experiences and lessons from international shale gas activities can be used to gain a better understanding of what to expect. Several of the studies described in section 4.1.3 have investigated either all possible environmental impacts or only that on water resource in South Africa. These studies were also based on international experience (see Appendix M). The anticipated risks and impacts were drawn from U.S. experience in particular, which has the most extensive record of shale gas activities as presented in Chapter 2 (e.g., Boyer et al. 2011; Brittingham et al. 2014).

Table 4.1 summarises key environmental impacts related to shale gas activities, which are based on the available impact-related data and information.

4.2.2. Findings presented in selected chapters of the SEASGD

As introduced in section 4.1.2, the SEASGD investigated the impact of shale gas development on the 17 selected topics based on four hypothetical scenarios. The topics were addressed by multi-author teams and reviewed by experts within the respective fields. Due to the uncertainty related to the future of shale gas development in South Africa, a risk assessment approach was followed in which the probability of occurrence and the severity of the consequence were estimated. This approach was followed for all significant stressors (e.g., disturbance) on each possible receiving entity type (e.g., sensitive ecosystem). Risk was then allocated as very low, low, moderate, high or very high. The assessment was done for four scenarios: 1) no shale gas production, 2) exploration only, 3) 'Small Gas' and 4) 'Big Gas' scenarios. These scenarios and a summary of all 17 topics and background information to the SEA process are presented in Appendix N.

Much of the SEASGD findings present a low risk associated with a scenario where shale gas is produced in the Karoo Basin, provided mitigation and management is diligently applied, and ecologically sensitive areas are avoided. A compilation of key findings from relevant (direct environmental) chapters of the SEASGD are included in Table 4.1 with impacts as identified in literature. A more detailed summary of the findings of Chapters 3 to 7 of the SEASGD are included in Appendix O.

Table 4.1 The author's compilation of known impact categories and impacts that have occurred in existing and past shale gas operations. Impacts are grouped according to exploration-, well construction- and production stages where hydraulic fracturing was included in the latter stages. A summary of the key findings of the SEASGD are given in the right-most column with the associated reference and chapter at the bottom of the table.

	International literature			Draft chapters of SEASGD
Impact category	**Exploration***	**Well pad/ -field construction**	**Hydraulic fracturing and production**	**All stages of shale gas development**
Habitat fragmentation/ surface impacts	• Land disturbance when exploration wells are drilled[1] • deforestation[1,3] • erosion[3] • site-specific short term disturbances[4]	• Development of well sites and additional infrastructure (e.g., roads and pipelines) • possible creation of edge effects[1,3] • soil compaction[4]	• Off-site disturbance due to sand extraction[4] • widespread habitat fragmentation from pipelines[4] • accidental release of chemicals, fuels, produced fluids or mud onto soil[5]	• Areas with high to very high ecological importance must be avoided to maintain the ecological integrity of the study area • ecological processes in the study area occur over large areas and are sensitive to disturbance • cumulative impacts from several and repeated impacts are a large risk of the Big Gas scenario[8]
Wildlife/ biodiversity impacts	Short term impacts varying with habitat[4]	Potential indirect impacts due to habitat loss and direct impact due to mortality impact from vehicles and industrial activities[1,3]		
Surface water impacts	Depends on water source used for exploration wells	• Affecting run-off and local hydrology[4,5] • sedimentation[4,5] • water quality impact[4,5]	• Possible surface spills of fracturing fluid, flow back water or hydrocarbons poses risk of introducing contaminents[1,3,7] • on- or off-site spills[4,5] • illegal dumping of waste water[1] • changes in hydrology[3] • waste fluids stored on-site are potential source of contamination[3]	• Water requirements during exploration stage expected to be 70 140 m^3 - 103 770 m^3 per drill rig, sufficient supply from current groundwater resources should be available • risk associated with surface spills of toxic material, which can be short-term and local, might cause downstream impacts[9]
Groundwater impacts	Depends on water source used for exploration wells	Potential for wells to form connections between deep shale gas formations and for shallow natural fractures to go into aquifers[1]		• Water needed for production activities advised to be sourced from outside the study area • risk of groundwater contamination during production stage • the potential contamination legacy of closed wells and the tracing of contamination are of concern[9]
Groundwater impacts		Improper well casing construction risks causing water contamination and methane migration[5]	• Degradation of water quality[2] • large quantities of water used[2,6,7] • upward migration of natural gas through leaking well casing or old wells[3,5,7] • accidental release of chemicals, fuels and produced fluids at risk of migrating towards groundwater[5,7]	

	International literature			Draft chapters of SEASGD
Impact category	**Exploration***	**Well pad/ -field construction**	**Hydraulic fracturing and production**	**All stages of shale gas development**
Induced seismicity			Micro-seismicity due to hydraulic fracturing process and higher risk of seismicity due to waste water injection into wells[1,2,3,6]	• Increased probability of small tremors around production wells in Big Gas scenario • risk of damage-causing earthquakes where hydraulic fracturing co-occurs with a fault line[10]
Waste	Drill cuttings and NORMS[1,4]		• Production of radioactive waste[2] • production of large quantities waste water[6] • local and off-site contamination from improper waste disposal[4]	• Substantial volumes of new waste types expected • NORMS, salinity and range of toxic chemicals make leach management and treatment a significant concern • deep-well injection and surface-dumping of waste water are prohibited[11]
Air quality	Emissions from operations and machinery[1,6]	Methane emissions while wells are tested[1]	• Methane leakage from wellheads[3] • release of volatile organic compounds or BTEX (Benzene, Toluene, Ethylbenzene and Xylenes)[1]	• Expected pollution during all stages of shale gas development from point- (e.g., well pad activities), mobile- (e.g., vehicles) and fugitive sources (e.g., leaking infrastructure components • pollutants include exhaust gas from vehicles, NO_2, Particular Matter, volatile organic carbons, silica and H_2S as a highly toxic gas[12]

References:

1 - (National Energy Technology Laboratory 2013); 2 - (Rivard et al. 2014); 3 - (Council of Canadian Academics 2014); 4 - (Brittingham et al. 2014); 5 - (Brantley et al. 2014); 6 - (Mauter et al. 2013); 7 - (Mauter et al. 2014); 8 - Chapter 7 (Holness et al. 2016); 9 - Chapter 5 (Hobbs et al. 2016); 11 - Chapter 6 (Oelofse et al. 2016); 10 - Chapter 4 (Durrheim et al. 2016); 12 - Chapter 3 (Winkler et al. 2016).

*Varies according to type of exploration (e.g., seismic surveys, exploration wells), but impacts can be expected to be localised and of short duration

4.3. Method

The method which was used for this chapter is similar to that of Chapter 3 where structured interviews and spatial data analysis contribute the bulk of the findings. Due to no on-the-ground shale gas development activities occurring in the Karoo Basin as of November 2016, no site visits were conducted. In addition to the review of international literature, the findings from the SEASGD were also included in this chapter. The SEASGD findings were not included in the initial design of this thesis, but were seen as a valuable addition given that the timing of this thesis coincided with that of the SEASGD. In sections 4.4.2 and 4.4.3, reference is given to the relevant method sections in Chapter 3, and differences specific to shale gas development are also described.

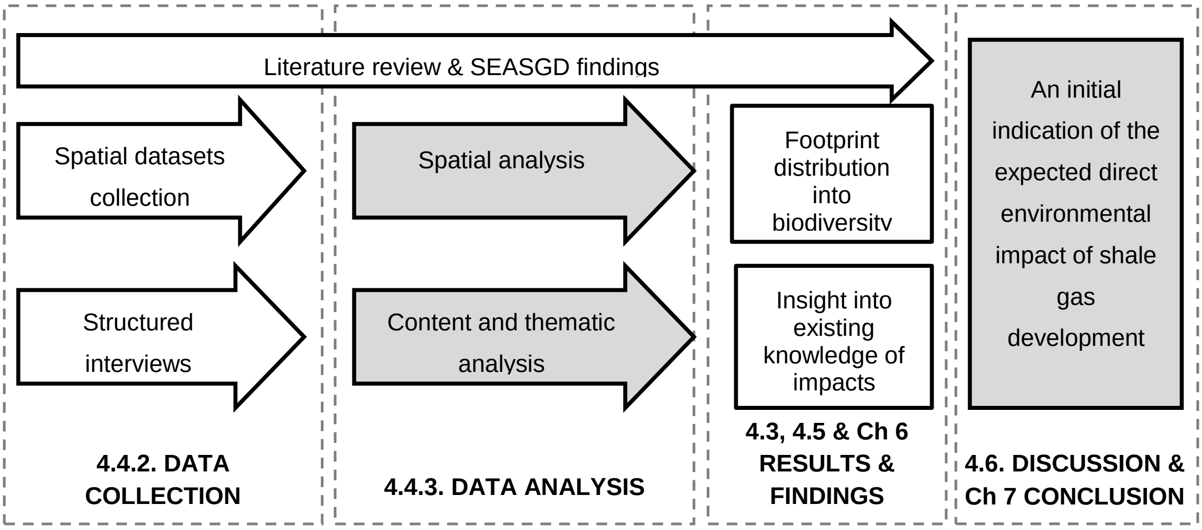


Figure 4.1 A schematic illustrating the mixed-method approach and an indication of the sub-sections of Chapters 3 and 4 where the results and discussion are presented.

4.3.1. Study area

The study area of approximately 171 811 km^2 is determined by the areas for which shale gas exploration rights have been received by the Petroleum Agency of South Africa (PASA). This area traverses the Eastern, Western and Northern Capes. Of all the biomes in this area, the Nama-Karoo, which makes up about 68% of the study area, will be most affected by the development. The location of each exploration area with respect to the biomes of South Africa is shown in Figure 4.9.

The Eastern Upper Karoo, Gamka Karoo and Western Upper Karoo have the most prevalent vegetation types within the study area. Karoo sediments such as shale and mudstones are most common in these vegetation types, but shallow soils with lime and occasional intrusive dolerites are also present throughout the landscape. The landscape varies from smooth to irregular and undulating plains with dispersed hills and outcrops of rocky areas in the west. The vegetation is predominantly represented by spiny and dwarf shrubs with low trees featuring throughout as well as 'white' grasses, especially after summer rain. Shrubby succulents are present towards the west. Annual rainfall varies from 100 mm in the west to 430 mm towards the east; rain is primarily received during autumn and summer. Minimum and maximum temperatures of -8°C and 38.1°C have been recorded throughout this area for July and January respectively (Palmer &

Mucina 2006; Mucina 2006a; Mucina 2006b). The Orange River Basin is also significant in this study area as it is the main drainage system within the Karoo Basin, with many of its tributaries flowing seasonally or temporarily (Esterhuyse et al. 2014). However, the catchments of the Gourits, Gamtoos, Sundays, Great Fish and Great Kei River overlap to varying extents with the southern part of the exploration rights applications area (DWAF 2006).

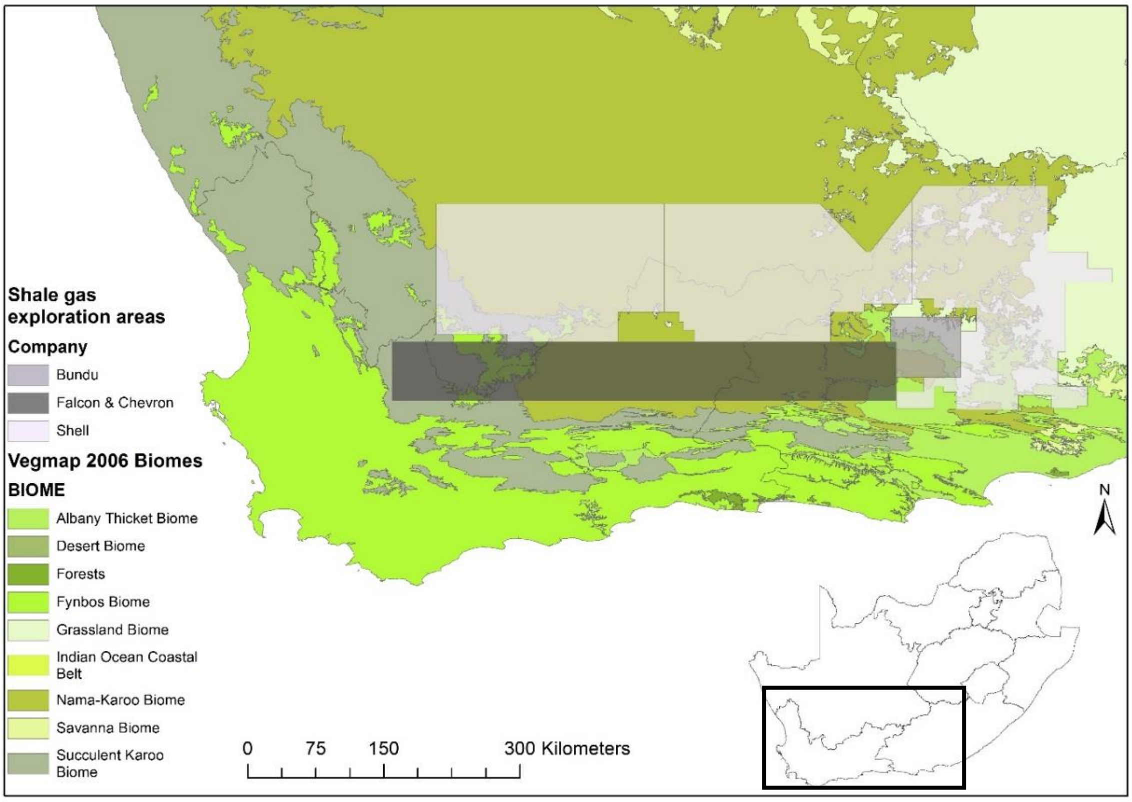


Figure 4.2 The study area which consists out of the areas where Bundu, Falcon and Shell have applied for Exploration rights in 2010 shown in relation to the distribution of the biomes of South Africa (Petroleum Agency of South Africa 2014).

4.3.2. Data collection

Structured interviews

The same interview form as that described in section 3.2.2 (Appendix D) was used here. Deviations from the interview process are described below.

For interviews on the potential impact of shale gas development, the minimum criterion for interviewees was to have knowledge of and/or past or present exposure to research related to the potential environmental impact of shale gas development in South Africa. Knowledge and/or experience with the SEA process which was ongoing in South Africa at the time of writing was regarded as a non-essential but valuable criteria.

Interviewees were invited to participate from the following expert groups: environmental assessment practitioners, researchers or research entities, specialists or consultants working in the field of environmental impact assessment, the state-owned utility, and entities engaged in policy/legislation development. A total of 15 interviews were conducted.

Spatial data

The spatial datasets summarising shale gas exploration right application areas was obtained from PASA and formed the basis of all GIS analysis. To obtain a regional understanding of the prospective impacts of shale gas developments, the exploration rights area dataset was also compared with various biodiversity and land use datasets. The majority of these datasets are available publically and/or from Government Departments. Table 4.2 summarises the titles and sources of these data sets.

Table 4.2 A summary of the spatial datasets used for the spatial analysis of the prospective footprint of shale gas development with a short description of each and the respective sources

Title of data set and year published ***Description***	**Source**
Shale Gas Exploration Areas 2014 *Areas where separate exploration entities have applied for exploration rights in the Karoo Basin*	Petroleum Agency South Africa (PASA 2014)
National Vegetation Map (Vegmap) 2012 *An update to the 2006 version of the same spatial dataset, describing floristically based vegetation units of SA, Lesotho and Swaziland*	South African National Biodiversity Institute (SANBI 2012)
South African Protected Areas Data Base Q1 2016 *Spatial dataset of the conservation estate of SA, including both formally protected areas and areas with a lower level of protection*	Department of Environmental Affairs (DEA 2016b)
National Protected Areas Expansion Strategy: Focus areas for protected area expansion 2010 *Areas identified through a systematic biodiversity planning process to determine large, unfragmented and intact areas very important for ecological persistence and biodiversity presentation*	SANParks (SANParks 2010)
Strategic Water Source Areas 2013 *SWSA are identified for South Africa, Lesotho and Swaziland and are areas supplying a disproportionate amount of annual runoff to geographical regions of interest*	Council of Scientific and Industrial Research (CSIR 2013b)
River catchment data 2006 *Shapefiles showing the river catchment areas of South Africa; classification of tributaries includes dry, perennial, non-perennial and those with unknown classification*	Department of Water Affairs and Forestry (DWAF 2006)

4.3.3. Data analysis

Structured interviews

The interview data analysis was mostly the same as for Chapter 3 (described in section 3.2.3).

In Section 4 of the interview form (Appendix D), numerical ratings were obtained for the severity and physical scale of the impact for three stages of shale gas development: exploration, construction, operation. The ratings ranged from one to five, the descriptions were the same as those presented in Chapter 3 and the description thereof is given with the results of this chapter in section 4.4.1.

Spatial analysis

The spatial analysis conducted in this chapter was similar to that of Chapter 3 (described in section 3.2.3). The datasets that were used (listed in Table 4.2) are slightly different from that of Chapter 3. The shale gas exploration rights applications area spatial dataset was used as the starting point for analyses to reveal insight into the prospective impacts of shale gas developments across the study area, with a focus on the Nama-Karoo.

4.4. Results

4.4.1. Interview results

Where permission was given, the interviewed expert groups were represented by the following entities: the Africa Earth Observatory Network at Nelson Mandela Metropolitan University, BirdLife South Africa, Council for Scientific and Industrial Research, World Wildlife Fund South Africa (WWF-SA), Umvoto Africa (Pty) Ltd, the Plant Conservation Unit at the University of Cape Town, SRK Consulting, Golder Associates Africa (Pty) Ltd and two entities requesting to remain unnamed. The highest relevant qualification of the interviewees were primarily in the fields of Environmental management, Geology or Geo-hydrology, Conservation Ecology and Environmental science, and these were distributed as follows: 7% Honours level, 57% Masters level, 36% PhD or higher. The number of responses obtained from the different expert groups is summarised in Table 4.3. In certain cases, interviewees also qualified for more than one expert group.

Table 4.3 A summary of the representation of the interviewees per expert group.

Expert group	Number of interviewees
Research entity	7
State utility	1
Designated authority	0
Registered environmental assessment practitioners	4
Representatives from Independent Power Producers	0
Legislation/policy developers	2
Specialists	6

After coding the interview data of all respondents (n=15), it was found that the responses can be grouped into four main themes where each theme has separate categories/sub-themes. The results for the first three themes are presented in this section, and the results of the fourth theme are presented and discussed in Chapter 5.

Theme 1: The anticipated direct environmental impacts from shale gas development

One of the first questions in the interview form asked if interviewees are aware of any adverse direct environmental impacts which shale gas developments have on the natural environment. To this question

73% of the interviewees (n=11) responded with a ‘yes’ and 27% of the interviewees (n=4) were unsure, no interviewees responded with a ‘no’.

Interviewees were asked to mention all environmental impacts related to shale gas development of which they are aware. Forty-six different potential impacts were recorded and coded in this section and then categorised into seven biophysical impact categories. The seven categories are listed and described in Table 4.4.

Table 4.4 A summary and description of the categories under Theme 1, direct impacts of shale gas on the biophysical environment (Biophysical impacts in short).

Biophysical impact category	Description
Atmospheric and audial	Includes atmospheric pollution, risk of methane emissions and leaching of toxic chemicals, impact of gas flaring at well pads, and visual, dust and audial impact.
Biodiversity and ecology	Impacts mentioned as 'biodiversity' or 'ecological' impacts and impacts with potential to have an effect on the dynamics between biological and physical ecological proxies. Risks such as land contamination, radioactive exposure and eco-toxicological impacts from waste products are also included.
Fauna	All mentioned impacts with specific relevance to animals.
Flora	All mentioned impacts with specific relevance to vegetation.
Landscape	Impacts on the land which transcends the boundaries of a development or refers to the impact of a development(s) on the landscape. Due to the potential extensive footprint, impacts related to risks of contamination are also included here.
Soil/ geological	Direct impacts relating to soil or geology.
Water	Resource quality and -size related impacts for both surface- and groundwater resources.

The total number of quotations per code within the various impact categories was obtained. The variation between the frequencies of quotations within the various impact categories and the most frequently recorded quotations are summarised per impact category, which are shown in Figure 4.3. The full record of codes and quotations of Theme 1 is included in Appendix P.

In addition to the impacts mentioned as direct environmental impacts, impacts related to the uncertainty and risk related to unknown parameters were also recorded throughout. The most frequently recorded code amongst these responses was that there are too many unknowns related to shale gas development in order to understand the impacts (n=4). This is a relatively overarching statement, but the full record of coded responses specifically relevant to the uncertainty of shale gas is presented in Appendix Q.

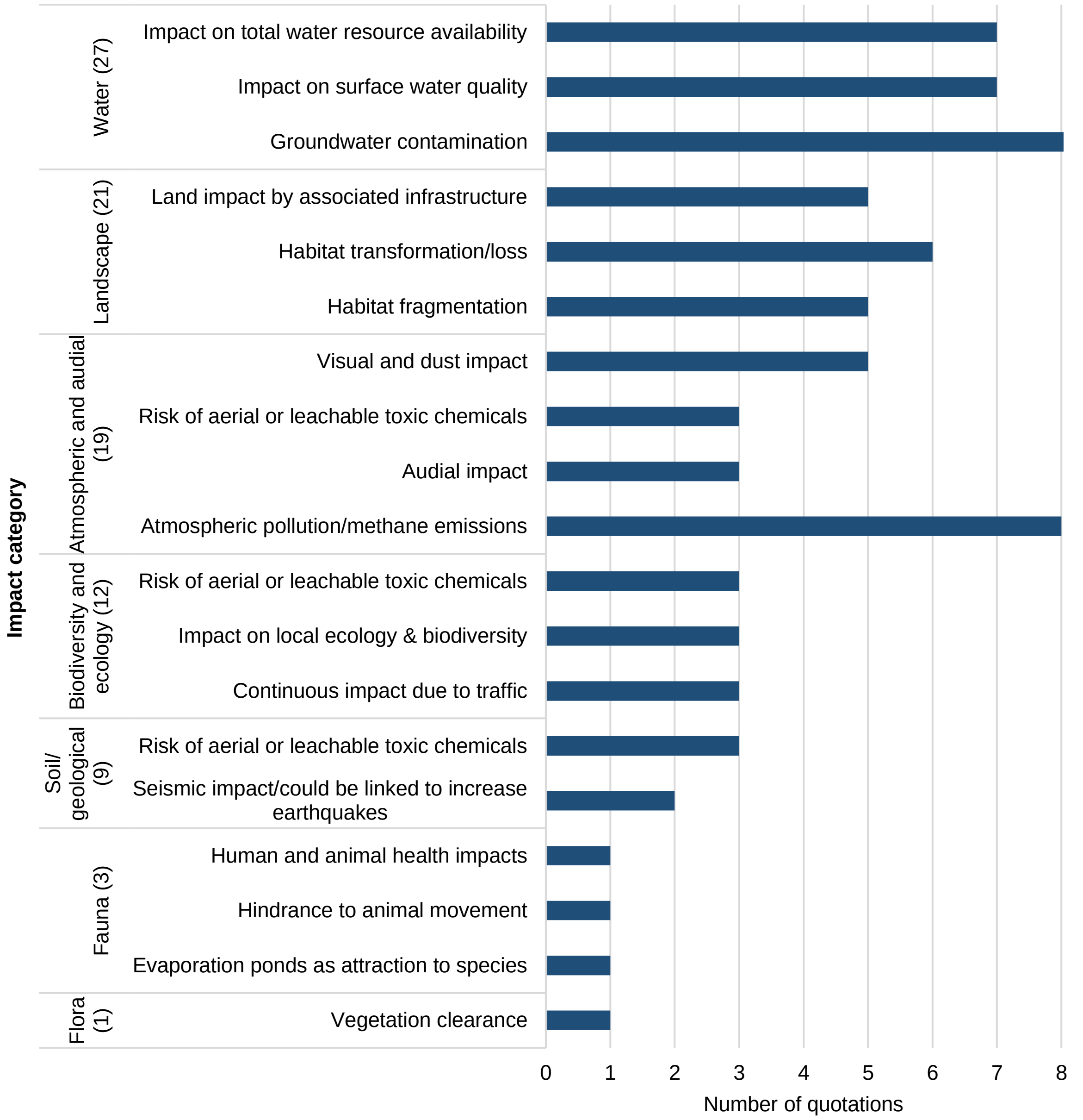


Figure 4.3 A summary of the most frequently mentioned biophysical impacts of shale gas development per impact category. A quotation represents a single event where the specific impact was mentioned.

Ratings were obtained from section 4 in the interview form for the severity and physical scale of the impacts during the different development stages; these were then recorded and analysed. Table 4.5 gives the descriptions of these ratings presented to the interviewees. Several interviewees commented that their ratings were given here on the assumption that the needed management actions or plans are in place. A summary of the number of ratings per numerical score value are presented in tables and plots in Appendix S. These ratings were used to calculate the medians, ranges and significant differences between development stages. It should be noted that a 'zero' score was used where interviewees were of the opinion that a specific impact is not relevant (as indicated in Table 4.5). However, all 'zero' scores were removed from the data in order to not 'pull' the median towards a lower value as the 'zero' does not reflect a relevant level of impact.

Table 4.5 An explanation of ratings attributed to the severity and scale of impacts on different biophysical elements and shale gas development infrastructure components.

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)

Figure 4.4 illustrates the difference in the medians and ranges (minimum to maximum) of ratings obtained for the impacts on different biophysical elements during the three stages of shale gas development. These ratings suggest that both the surface water and groundwater quality and quantity impacts are expected to be low during the exploration and construction stages, but the severity and physical scale of these impacts are expected to increase during the production stage. The median rating for the severity of the impact on all biophysical elements during exploration was ‘2’, except for soil which was ‘3’. The highest median rating was obtained for the severity of the impact on groundwater usage during production, which is in accordance with the other findings of Theme 1.

Figure 4.5 shows the medians and ranges of the ratings obtained for the severity and physical scale of the impacts from the different infrastructure components during the three stages of development. The impacts from almost all (*i.e.,* excluding well-casing construction) different shale gas infrastructure components were higher during the construction and production stages as well as more severe and at a greater scale. The lowest rating was obtained for the severity gas infrastructure during exploration, which confirms that interviewees do not expect gas infrastructure during the exploration stage. Overall, the highest median rating was obtained for the severity of waste water disposal during production.

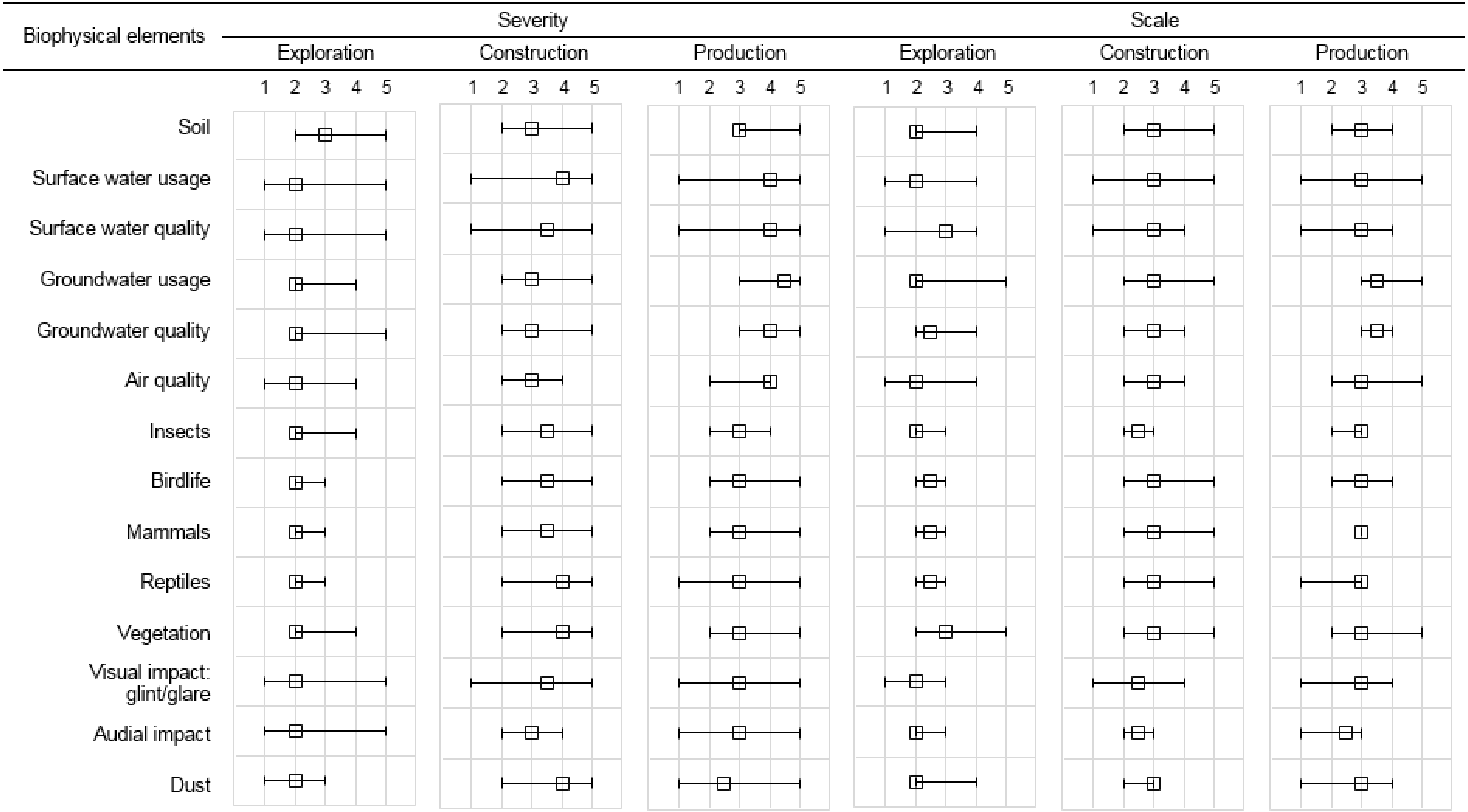


Figure 4.4 The median and range (minimum to maximum) of ratings obtained for the severity and physical scale of impacts on various biophysical elements during the exploration, construction and production stages of shale gas development (n=15).

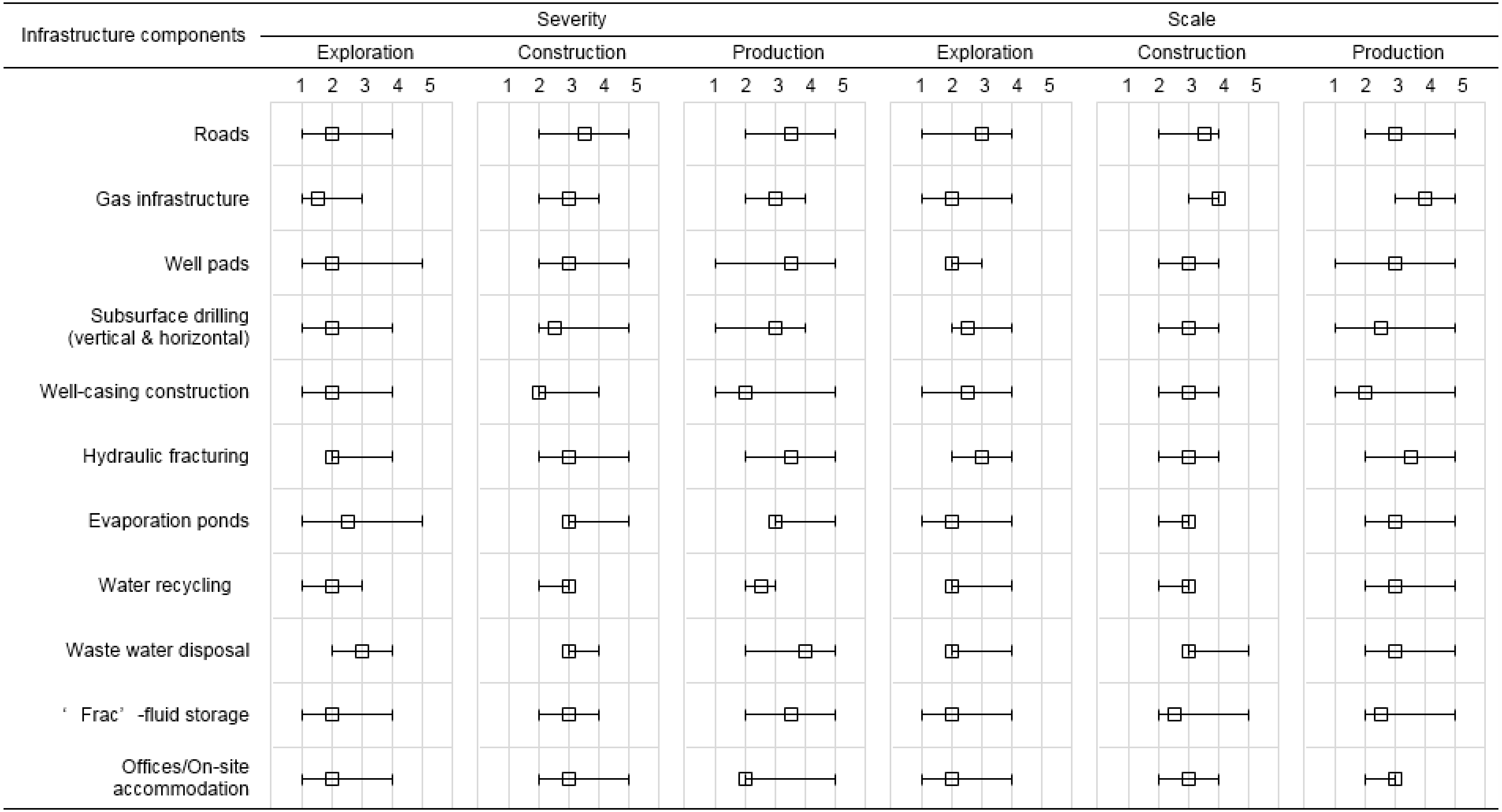


Figure 4.5 The median and range (minimum to maximum) of ratings obtained for the severity and physical scale of impacts from various infrastructure components during exploration, construction and production stages of shale gas development (n=15).

In addition to plotting the median and range of ratings, Tables 4.6 and 4.7 summarise the results from the Mann–Whitney U test, which tested for significant differences in the ratings between the different development stages. All other p-values for the difference in biophysical element and infrastructure component impact ratings between the three development stages are given in Appendix R.

The difference in the ratings for groundwater quality and quantity impacts between 1) construction and production and 2) exploration and production were found to be almost consistently significant ($p < 0.03$) both in terms of severity and physical scale (Table 4.6).

Table 4.6 A summary of the biophysical elements for which there was a significant difference (p<0.05) in the ratings of impact severity and scale between the three different stages of shale gas development [A]. The p-value is given in brackets.

Measure	Exploration/Construction	Construction/Production	Exploration/ Production
Severity	Groundwater usage (0.001)	Soil (0.047)	Groundwater usage (0.001) Groundwater quality (0.004)
Physical scale		Groundwater usage (<0.001) Groundwater quality (<0.001)	Groundwater usage (0.023) Groundwater quality (0.002)

[A] Results from Mann-Whitney U test, n=15, p-value used = 0.05; full results in Appendix R

Table 4.7 A summary of the infrastructure components for which there was a significant difference (p<0.05) in the ratings of impact severity and scale between the three different stages of shale gas development [A]. The p-value is given in brackets.

Measure	Exploration/Construction	Construction/Production	Exploration/ Production
Severity	Roads (0.010) Well pads (0.003) Subsurface drilling (<0.001) 'Frac'-fluid storage (0.037)		Roads (0.012) Well pads (0.044) Subsurface drilling (0.012) Evaporation ponds (0.034) 'Frac'-fluid storage (0.012) Offices/On-site accommodation (0.036)
Physical scale		Evaporation ponds (0.002)	Well pads (0.024) Evaporation ponds (0.023) 'Frac'-fluid storage (0.038) Offices/On-site accommodation (0.018)

[A] Results from Mann-Whitney U test, n=15, p-value used = 0.05; full results in Appendix R

The results, showing significant differences in ratings of impacts by the different infrastructure components, indicate the definite difference in expected impacts from such components during the three shale gas development stages (Table 4.7). A significant difference was especially found for the impacts during exploration versus construction as well as exploration versus production. However, the results do not offer any significant difference from the expected impacts of infrastructure components during construction versus production, except in regards to the evaporation ponds.

Theme 2: Comments on EIA process and applicability for shale gas development

This theme represents feedback from the interview process where interviewees had comments regarding the EIA process in general and includes the occasional comment on the applicability thereof to shale gas. Many of the responses given to this section were suggestions for which the EIA process can be amended and/or suggestions for minimising and managing impacts, which links to Theme 4.

All interviewees (n=15) were asked if they think the current EIA process sufficiently covers all possible shale gas-related impacts on the biophysical environment. The majority of interviewees replied 'no' (n=8), two were unsure, and the rest replied 'yes' (n=5). Some interviewees furthered their response with a comment, which was also coded, and those comments mentioned more than once are summarised in Figure 4.6.

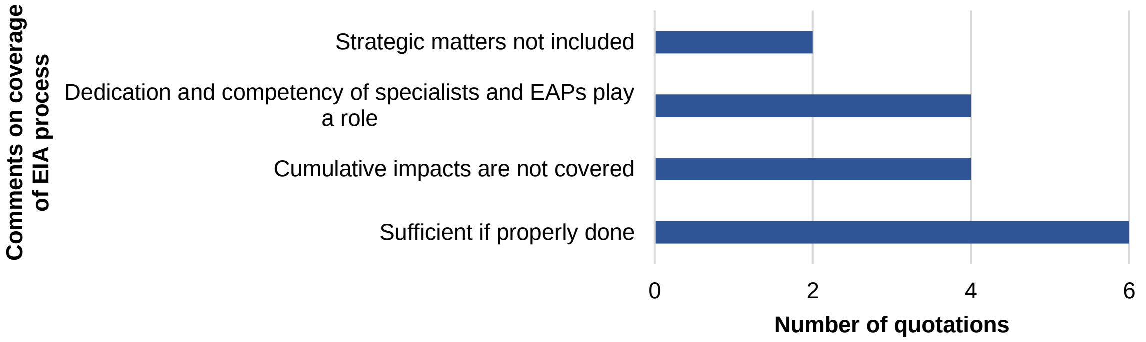


Figure 4.6 Summary of similar comments in response to the question of the sufficiency of the EIA process to capture all possible environmental impacts of a project.

In addition to the comments regarding the EIA process, an interviewee from WWF-SA commented on the appropriateness and applicability of NEMA (Act no. 107 of 1998) and the current EIA regulations to conventional mining. This interviewee stated that these regulations were not designed for the widespread range of impacts associated with shale gas development and that separate legislation was needed for unconventional energy (and mining). Interviewees were specifically asked which impacts of shale gas development they expect not to be covered sufficiently under the current EIA process and regulations. The following responses were recorded:

- Atmospheric pollution or methane emissions
- Cumulative impacts
- Decommissioning/well abandonment
- Groundwater contamination
- Long-term impact on environmental change
- Impact of fracturing fluid
- Recycling and end-of-life challenges
- Wastewater treatment not covered sufficiently

The SEASGD and desktop studies, which include the identification of possible development sites are part of the early stages of the EIA process and impact identification. The quality of these datasets is thus important as an early impact avoidance measure.

Interviewees were asked if they know what datasets are being used for shale gas development baseline studies and in the SEASGD, to which 87% (n=13) replied 'yes' and 13% (n=2) replied 'no'. Frequently mentioned datasets included the National Vegetation Map or other SANBI datasets, data from the Council of Geoscience, a hydrogeological map and heritage resource maps. In addition, interviewees who knew which datasets are being used were asked if existing field survey archives, spatial datasets and maps were sufficient to predict the impact of shale gas development in South Africa, to which 8% (n=1) replied 'yes', 85% (n=11) replied 'no', and one interviewee was unsure. One interviewee made the following encompassing statement: "*Datasets which are being used is used under the assumption that the field conditions are known, which is not the case*." These responses were supported by comments and suggestions in some cases; the most frequently recorded responses are summarised in Table 4.8.

Table 4.8 Most frequently recorded comments and suggestions to the sufficiency of datasets used to inform shale gas developments (e.g., field survey archives, spatial datasets and maps).

Comment/Suggestion	Frequency recorded
Current datasets and maps have insufficient resolution and/or are outdated, especially so in arid regions	10
Ground-truthing and more engagement with specialists are necessary (verification of features represented in a spatial dataset with field investigation)	5
Datasets need to be updated and made publically available, not commoditised	3
Information on quantity and quality of water sources (and deep groundwater) in Karoo is very limited	3
Monitoring campaign needs to be implemented	3
Immediate funding should go towards baseline studies	2

Theme 3: Feedback and reference to SEASGD process

Following the feedback on the EIA process in Theme 2, three interviewees voluntarily offered feedback on the expectations and value of the SEASGD. This feedback is summarised in four distinct points:

1. A comment that the SEASGD was done too late
2. An expectation that the outcome of the SEASGD will highlight the need for baseline studies prior to shale gas development
3. A comment that specific monitoring and management of impacts are receiving special attention in the SEASGD with respect to the dynamics between other activities across the wider areas (e.g., urbanization and mining); recommendations are being made based on regulations
4. Affirmation that the SEA does not replace EIAs and that site specific impacts still need to be taken into account

Theme 4: Input regarding management and mitigation measures and interview findings from study scope

The results under this theme are to a certain extent interlinked with the first three themes, but the results indirectly and directly related to impact management and mitigation are discussed in Chapter 5.

Responses that fell outside of the scope of this study were also recorded, including indirect impacts, socio-economic impacts and impacts after the production stage. These responses are presented in Appendix T.

4.4.2. Results from spatial analysis

Impacts on biomes and vegetation types

The shale gas exploration right application areas were used to calculate the area and percentage per biome type within the exploration applications area as well as the percentage of the total biome area falling within the exploration applications area. Table 4.9 summarises the areas per biome overlapping with that of the total study area as well as the proportion of each biome within the exploration area. These results indicate that the majority (68.44%) of the exploration area consists of the Nama-Karoo, and this area represents more than a third (34.37%) of the Nama-Karoo in total.

Table 4.9 The area per biome within the area of shale gas exploration rights. The proportional area of each biome and the percentage of the total biome's area are also indicated.

Biome	Total area which application rights have been applied for per biome (km^2)	Percentage per biome within exploration area	Percentage of total biome size within exploration area
Nama-Karoo Biome	85331.1	68.44%	34.37%
Grassland Biome	14375.7	11.53%	3.97%
Succulent Karoo Biome	8809.2	7.07%	11.48%
Albany Thicket Biome	6790.8	5.45%	23.31%
Azonal Vegetation	5665.6	4.54%	17.66%
Fynbos Biome	3673.2	2.95%	4.07%
Forests	37.9	0.03%	0.73%
Totals	**124 683.5**	**100%**	**9.84% (of total of all biomes)**

The shale gas exploration applications were also used to calculate the percentage of various vegetation types within the exploration right applications area. The Western Upper Karoo was found to have the most affected types of vegetation, representing approximately 30% of the exploration area. The Gamka- and Eastern Upper Karoo were found to be the second and third most affected, both representing approximately 12% of the exploration area. More detailed results for this analysis are presented in Appendix U.

Impact on protected areas, Strategic Water Source Areas and river catchments

Similar to the analysis using biome and vegetation type areas, the area per protected area type was calculated followed by a calculation of the total percentage within the protected area type classified as Nama-Karoo. Table 4.10 summarises the areas per different protected areas falling within the study area. It was found that 'Protected Environments' and 'Nature Reserves' each make up approximately a third of the conservation estate, which is located within the exploration area. By far, the majority of 'Protected

Environments' and 'Biosphere Reserves' in the exploration area is classified as Nama-Karoo. The location of protected areas relative to the exploration area can be seen in Figure 4.7.

Table 4.10 The area of different protected area types within the shale gas exploration rights applications area and an indication of the percentage of the aforementioned area classified as Nama-Karoo.

Protected area type	Total area within study area (km^2)	Percentage of total protected area type classified as Nama-Karoo
Protected Environment	395.9	79.07%
Nature Reserve	368.4	43.54%
National Park	240.8	-
Biosphere Reserve	63.3	96.37%
Total	**1068.4**	**-**

The proximity of protected areas to the study area was also investigated and it was found that three national parks (Karoo National Park, Addo Elephant National Park and Camdeboo National Park) and seven nature reserves were less than five kilometres from the exploration application areas. An additional eight nature reserves were found to be between five and eight kilometres from the exploration areas.

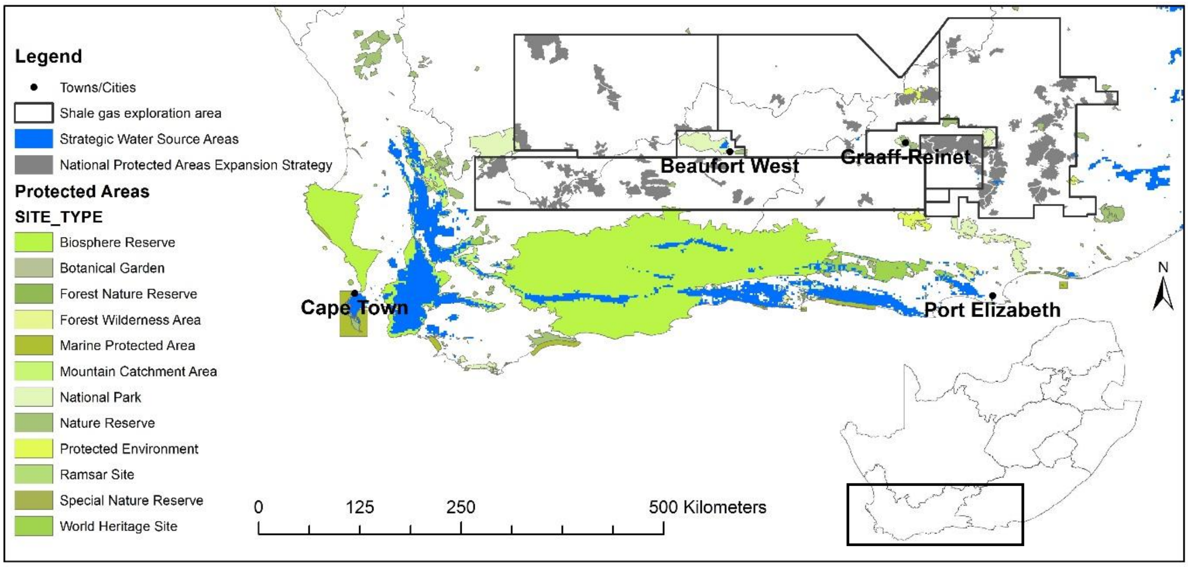


Figure 4.7 The shale gas exploration areas' location relative to that of SWSA, areas identified in the NPAES and different types of Protected Areas (South African National Parks 2010; Petroleum Agency of South Africa 2014; Department of Environmental Affairs 2016b; Nel et al. 2013).

It was assumed that shale gas developments are less likely to be located within already-existing protected areas than in areas not-yet protected, albeit earmarked through the National Protected Area Expansion Strategy (NPAES) last updated in 2010. The location of these NPAES focus areas and shale gas exploration areas was thus analysed to determine how much of the development area falls within areas allocated and identified as intact and unfragmented. These are areas of high importance for ecological persistence and biodiversity representation suitable for the creation or expansion of large protected areas. It was found that a total of 13 641.7 km^2 was located within NPAES focus areas, of which 4468.5 km^2 (32.76%) are classified as Nama-Karoo.

It was found that the study area overlaps with 65.42 km^2 of Strategic Water Source Areas, but as can be seen in Figure 4.7, the overlap is minimal as the majority of the country's SWSAs are located along the East Coast, the Kwa-Zulu Natal highlands and the southern cape.

A simple calculation was done to determine length of the tributaries of the seven river catchment areas which fall within the shale gas exploration area. The proportions of the different catchment areas inside the exploration area were subsequently calculated. It was found that the catchment areas of the Great Fish River, Gamtoos River and Sundays River have the highest proportion of tributaries inside the exploration area at 72.7%, 57.3% and 54.3% respectively. The total lengths of these tributaries are classified as non-perennial, perennial and unknown. Due to the nature of the data available and the scope of the study, no analysis was done to investigate the direction and magnitude of flow within these catchment areas. The full results are included in Appendix T, and the location of the river catchment areas can be seen in Figure 4.8. To indicate the low rainfall across the study area, a mean annual precipitation map is included as Appendix V.

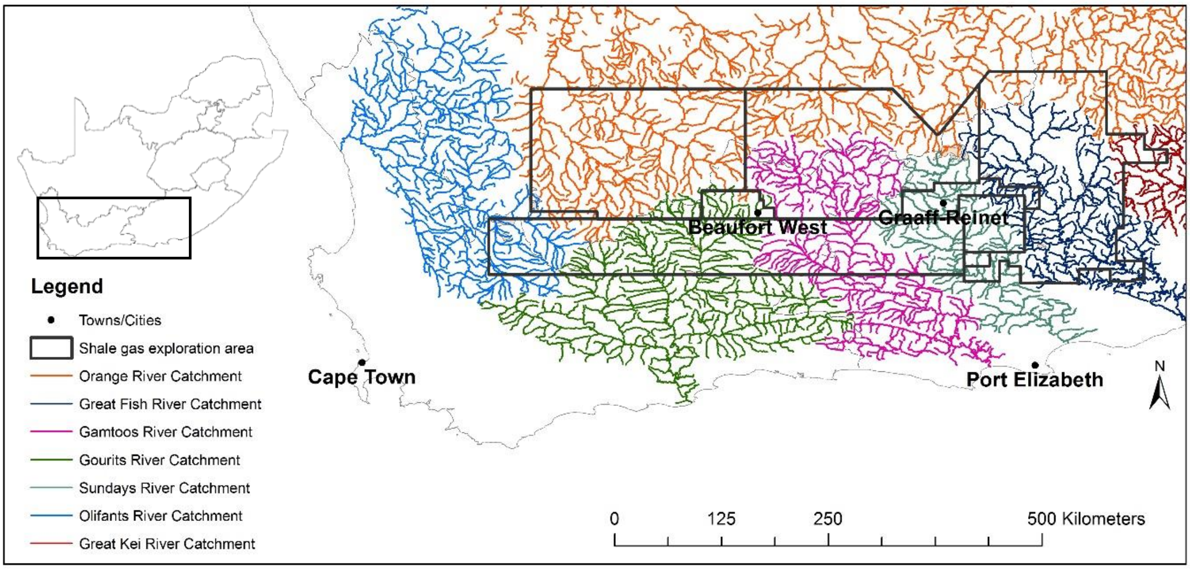


Figure 4.8 The shale gas exploration areas' locations relative to that of traversing river catchment areas (DWAF 2006).

4.5. Discussion

4.5.1. Synthesis of findings

The interview results suggested the impact on water resources and landscape impacts such as habitat transformation and –fragmentation are the primary concerns related to the direct environmental impact of shale gas development. These findings are in agreement with that of previous studies done in South Africa, with particular relevance to the impact on water resources (Steyl et al. 2012; Vermeulen 2012; Bole-Rentel 2015). The results showing the concerns regarding impacts on water resources have been presented in a relatively general sense, and they do not specifically address the various specific impacts as identified from international literature and the findings of the SEASGD. However, the impacts such as gas migration into aquifers and water recycling (Brantley et al. 2014) need to be assessed according to the water source and specific hydrogeological factors in the Karoo Basin (Steyl et al. 2012).

The study area is already water constrained; this has been highlighted as a key issue related to shale gas development in the Karoo and is included in the findings of the SEASGD (De Wit 2011; Steyl et al. 2012; Hobbs et al. 2016). Although no detailed analyses were conducted regarding the impact on groundwater or surface water quality or quantity in the study area, the study area is co-located with a large area across the Karoo Basin, which is classified as a major aquifer yielding 'good quality' water (Department of Water Affairs 2012). Nonetheless, the quantity remains constrained with the majority of the study area receiving less than 200 mm rainfall annually (Appendix U). The finding that approximately 19 858 km of tributaries from seven river catchment areas are exposed in the exploration area accentuates the concern for the impact of shale gas development on water resources in this water scarce environment.

The water quantity requirement, the source thereof, the limited capacity for waste water treatment in these areas (Oelofse et al. 2016), and the uncertainty with regards to undocumented groundwater resources as was found from the first borehole of the KARIN project (de Kock et al. 2016) further supports the fact that the potential water impacts associated with shale gas production are rated as high risk from several perspectives. The uncertainty related to the plans and implications of shale gas production was also notable from the interview results. The following comment was made by a researcher who had contributed to a national study about the impact of shale gas development on South Africa's water resources: "*Developing shale gas is a low likelihood and high impact activity. There are multiple impacts which are not well understood; new impacts come to light every day in countries with shale gas developments. Cause and effect is hard to link, which gives much room to prospecting companies to get away with impacts. The impact and dispute of contamination of gas is not well understood and very hard to prove how it happens and/or what the pathways are."*

In addition to the uncertainty of the expected impacts, the characteristics of South Africa's deep groundwater resources (>300 m) are still largely unknown (Woodford et al. 2013), which makes it impossible to determine anticipated impacts let alone measure them. In the light of this uncertainty, an interviewee explicitly commented that the precautionary principle should be applied. All further responses related to the uncertainty of the impact of shale gas development is summarised in Appendix Q. Overall, the interview results, the SEASGD findings and lessons from literature jointly confirm the increase in impacts and the effects of impacts on ecosystems from the exploration stage towards production as discussed by (Brittingham et al. 2014).

The proportion of the total are in the Nama-Karoo affected by the study area (34.37%) is relatively high considering that only approximately 2% of the biome is under formal protection (DEA 2016). Although the vegetation types found represent more than 5% of the study area, all have a conservation status classified as 'Least threatened' (Mucina & Rutherford 2006). These findings need to be put in context of the findings from the SEASGD where areas of high and very high ecological importance were identified as those to avoid in order to keep the ecological integrity of those areas intact (Holness et al. 2016). A potentially valuable future investigation will be to determine if the NPAES areas falling within the study area overlap with the ecologically important areas identified in the SEASGD.

The basic spatial analyses presented here were done for the entire exploration area as applied for by Shell, Bundu and Falcon. The exploration area is similar to the area investigated in the SEASGD, but the footprint of exploration activities are expected to be focussed on small areas within the exploration area, pending the preliminary identification of areas with access to the resource. The identification of possible exploration drilling sites have been made by Shell and Bundu (Golder Associates 2013; Golder Associates 2015), and preliminary identification of seismic survey lines have been identified by Falcon (Fourie 2015). A secondary step would be to use the results of the exploration to determine where production wells should be situated, but no information was available to investigate the location and extent of areas that would be affected by production. Mapping of potential areas ideal for development activities (*i.e*., eliminating areas that are not suitable for development such as towns, wetlands, etc.) as done in the (Holness et al. 2016) and by Golder Associates for Shell (Golder Associates 2013) would thus be needed to safeguard sensitive areas from exploration and production activities. After such mapping, the potential environmental impacts of the narrowed-down areas should be investigated at a site-specific level.

In the SEASGD, the landscape impacts were assessed based on the assumption that the development activities will be limited to four 30 x 30 km blocks (CSIR 2016). This assessment provides an interesting basis for arguing how shale gas development infrastructure should be optimally located to minimise environmental impact. Based on the findings from exploration activities about the location of economic shale gas reserves, a trade-offs analysis (Milt et al. 2016) for the location of well pads, roads and pipelines could be considered to determine if an intense and focussed distribution is preferable to a less intense and dispersed distribution of well pads and associated infrastructure. Should this approach be followed, it is possible that the proportion of potentially affected tributaries in the different river catchment areas can be minimised. The findings of the SEASGD also indicated that the contribution from roads to habitat transformation can be significant and represent approximately 11% of the total transformed area in the scenario where activities are limited to 30 x 30 km development blocks (Holness et al. 2016).

The omission of cumulative impacts in the EIA process was regarded as a weak area in terms of planning for multiple impacts in a larger development area. However, the aforementioned feedback was given under the assumption that the EIA process will be used in its current form for the assessment of shale gas activities and needs to be interpreted within that context. To this assumption, the comment of an interviewee suggesting a customised EIA process for unconventional mining is particularly relevant. In the event that shale gas development progresses to the construction and production stages, adherence to environmental management practices is of utmost importance to reduce risk pertaining to impacts on all strategic topics assessed by the SEASGD (CSIR 2016b).

The interviews provide strong evidence for the notion that currently-used spatial datasets are not sufficient to determine baseline conditions, predict the impact of shale gas development or inform optimal siting of activities. Moreover, the feedback that these datasets are outdated, particularly those for arid regions, is immensely relevant. An interviewee with experience in the EIA process as a specialist and contributor to the SEASGD commented that "*Data coverage in Karoo is extremely poor. The area occupies about 27% of the country but occupies about 5% of the available data."* This feedback links strongly with that of the SEASGD Chapter 7 on Biodiversity and Ecology (Holness et al. 2016). In the aforementioned chapter, the determination of baseline conditions was a strong recommendation prior to the commencement of shale gas development as being pivotal to predict context-specific impacts.

4.5.2. Landscape outlook

Two aspects that need to be assessed with an ecosystem approach are 1) the widespread nature of shale gas resource under investigation and 2) the cumulative impacts arising from multiple impacts that are repeated and distributed across the affected area. Even if shale gas activities are concentrated within a number of 30 x 30 km blocks, the nature of a well field's development is such that it creates a 'network' of transformed area (CSIR 2016b) from the added roads, pipelines, compressor stations and water holding infrastructure (Drohan et al. 2012). Figure 4.9 gives an example of how an area can be transformed by shale gas development.

Figure 4.9 An example of how shale gas development transforms small areas in a distributed manner when a wellfield is developed. The image on the left is satellite imagery from 2005 of an area northeast of Waterville, Pennsylvania, U.S. The image on the right is satellite imagery from 2014 of the same area. In each case, the image represents a block of approximately 10 km x 6 km. Photo credit: Google Earth.

Furthermore, the network of activities and impacts associated with shale gas development are expected to evolve over the different stages in a timeframe of between 2-30 years. This timeframe excludes time of decommissioning, which could add another five to ten years, as well as time for rehabilitation to occur, both of which would require continued monitoring (CSIR 2016b). Stressors to ecosystems in the study area could thus arise from cumulative impacts (Treweek 1999). These impacts include not only those expected across a large geographical area, but those potentially lasting for a longer and unspecifiable duration. The so-called 'legacy wells', referring to improperly sealed wells which are also relevant in conventional oil and gas industry (Dilmore et al. 2015), add further risks here. These wells were mentioned as a concern at least once during the interview process and are listed as an aspect that is lacking in the current EIA process.

From U.S. experience, a matter that contributes to landscape-wide risks is the lack of transparent data and access to data to effectively measure long-term effects on water resources in particular (Brantley et al. 2014), but also biodiversity in general (Kiviat 2013). In combination with the limited knowledge of deeper groundwater resource characteristics in South Africa (Woodford et al. 2013), management plans and regulations would need to be designed in the absence of such impacts, baseline data or lessons from local experience.

In an ecological impact assessment it is recognised that full survey and characterisation of all ecosystem components can be too timeous and expensive. It is, therefore, necessary to focus on a limited number of ecosystem parameters. Focussing procedures then involve the identification of key biological components and processes as valued ecosystem components (VECs) to use as focal points for impact assessment. Such VECs are selected based on their value in terms of predetermined criteria such as usefulness as an ecological indicator, economic value or societal benefit. Since an abiotic component of ecosystems needs to sustain biotic components, water is an ecological attribute which can be selected as a VEC (Treweek 1999). In the case of the water scarce Karoo environment (Hobbs et al. 2016), assessing the impact on water and other potential VECs could thus provide a focussed understanding of the potential influence on receiving ecosystems.

Landscape transformation can occur in three basic ways: suddenly, gradually or with temporary unstable change. These often overlap and coincide with the dynamic processes experienced by its vegetated elements, and the scale at which these are experienced determines where that system is then placed in succession (Ingegnoli 2002). In the case of the Karoo, gradual transformation is expected during the exploration stages, but depending on the size of the resource available (if found) (Holness et al. 2016), a more sudden change may result. This change, furthermore, may be overlapped with temporary instability, depending on the extent of rehabilitation to be implemented. There is concern for subjecting the Karoo landscape to further significant transformation associated with energy developments (Milton & Dean 2015), but based on findings and international experience, this might be unavoidable if an economically viable shale gas reserve is pursued in the Karoo Basin. Nevertheless, if in the future landscape alteration in the study area occurs at ‘eco tissue’ level (integrated range of spatial- and temporal scales and “*a set of thematic mosaics*” (Ingegnoli 2002; p. 56) related to different land uses), the landscape can be diagnosed with a landscape syndrome in order to identify interventions. For such diagnosis, the reference conditions (*i.e.,* baseline) of the environment are needed (Ingegnoli 2002), which again highlights the risks associated with the uncertainty related to baseline conditions within the Karoo (De Wit 2011; Woodford et al. 2013; Winkler et al. 2016; Holness et al. 2016).

4.6. Conclusion

Shale gas exploration activities could have relatively minimal impacts depending on the techniques used (Brittingham et al. 2014; Holness et al. 2016). Thereafter, into the construction and production stages, impacts are expected to increase in number and in geographical distributions with effects that are currently largely unknown due to the lack of specific location of activities and known environmental parameters. These impacts of which water resources was highlighted as a specific concern are expected to increase in geographical distribution and magnitude. The three-dimensionality of shale gas development in the Karoo Basin combined with unknown baseline conditions and significant threat to already-constrained water resources thus presents limitations to the depth at which these impacts can be studied prior to the start of development. However, risk associated with the impacts of shale gas development could be minimised. One way of doing so is through the application of the precautionary principle where development is limited until the subject is better understood (O’Riordan 1994). This principle is seemingly essential for every scenario of shale gas development in the Karoo.

Notwithstanding the scope of this chapter, a wider understanding of the impact of shale gas development in the study area landscape would require the inclusion of impacts outside the scope of this study. The findings presented here are expected to be a valuable contribution toward a holistic investigation where impacts extend well beyond the natural environment (e.g., Atkinson et al. 2016; Chapman et al. 2015).

CHAPTER 5: FINDINGS AND RECOMMENDATIONS FOR MANAGEMENT AND MITIGATION OF IMPACTS

Previous chapters presented findings on the direct impacts of solar power and shale gas developments (Chapters 3 and 4 respectively) in the Nama-Karoo and Savanna. Recommendations for management and mitigation measures are important for minimising the impacts and effects of these impacts into the future.

5.1. Introduction

Well drawn-up environmental legislation has emerged from the Constitution of South Africa (RSA 1996) with the National Environmental Management Act (NEMA) (Act no. 107 of 1998) (RSA 1998) as the overarching Act. The success of this policy has been limited, however, by the implementation, compliance and enforcement thereof (Rossouw & Wiseman 2004). The findings of this thesis suggest that, while improvements to some aspects of the Environmental Impact Assessment (EIA) process could be made, as regulated under the NEMA (Act no. 107 of 1998), it is an effective policy tool if sufficiently implemented.

After an EIA has been approved for a proposed development, anticipated adverse impacts can, to a degree, be mitigated. EIA legislation, therefore, often includes sections for impact mitigation (Treweek 1999). In South Africa, provision is made for mitigation in the EIA Regulations of the NEMA (Act No. 107 of 1998). The purpose of the EIA Regulations is to provide environmental authorisations for planned activities, to avoid or mitigate adverse environmental impacts and to increase the likelihood for positive impacts to occur. One of the objectives of the EIA process is linked to this purpose: *"…through a consultative process determine the…degree to which these impacts can be reversed; may cause irreplaceable loss of resources, and can be avoided, managed or mitigated"* (RSA 2014; pp. 52). Furthermore, impact management objectives are to be included in the environmental management programme (EMPr) as well as a proposal for alternatives in response to impact avoidance, mitigation and management measures identified through the impact assessment process. An EMPr is expected to include all avoidance, management and mitigation measures for all phases of a development from planning and design to rehabilitation and closure where applicable (RSA 2014).

Ecological impact mitigation includes a range of deliberate actions whereby adverse effects are addressed; these can include controlling the sources of impacts, or limiting the exposure ecological receptors receive from impacts (Treweek 1999). Management, as used in the context of the EIA process in EMPrs and environmental management systems (EMSs), provides a framework within which mitigation actions are performed (Marshall 2002). Table 5.1 provides a summary of examples of the different types of ecological impact mitigation related to solar and/or shale gas, including examples that were witnessed during solar power plant site visits.

Table 5.1 Ecological impact mitigation types with examples for solar power and unconventional hydrocarbon development (Treweek 1999; Northrup & Wittemyer 2013).

Type of mitigation with general example	Example in solar power development	Example in unconventional oil or natural gas development
Avoidance		
- Sensitive design and avoidance of key ecological areas	Restricting development in- and in close proximity to ecologically sensitive habitat	Restricting development in- and in close proximity to ecologically sensitive habitat
Reduction, moderation, minimization		
- Emission or leakage controls; Enabling wildlife access and movement	Allowing wildlife to move into and out of solar field	Avoiding leakage of well casings or fracturing fluid containers
Rescue		
- Relocation or translocation of plants and animals	Creation of green areas for sensitive plant species	Maintenance of refuge areas
Repair, reinstatement, restoration		
- Habitat reinstatement or vegetation re-establishment	Topsoil restoration in solar field	Well pad rehabilitation or revegetation
Compensation		
- Donation or creation of alternative/substitute sites	Restoration or protection of alternative sites where ecologically sensitive sites cannot be avoided	Restoration or protection of alternative sites where ecologically sensitive sites cannot be avoided

The objective of this chapter is to highlight results from the interviews presented in Chapters 3 and 4, which relate to the management and mitigation of environmental impacts of current and planned solar power developments and shale gas developments in the arid interior of South Africa. The aim is for these findings to provide relevant guidance for the applicability of the measures during the EIA process or practically during developmental activities (*i.e.,* exploration, construction or operation/production). The synthesis of the aforementioned findings and additional recommendations then ideally would provide guidance to the management and mitigation related to impacts from future alternative energy development in the Nama-Karoo and Savanna biomes from a strategic and integrated perspective. Reviews and reports of mitigation measures have been published for the impacts of solar power and shale gas internationally (e.g., Walston et al. 2015; Arthur et al. 2010). However, the focus here was not to provide a summary of all known mitigation measures available, but rather limit discussion to such measures and actions found throughout this thesis.

5.2. Management and mitigation for the impacts of solar power

5.2.1. Existing practice and policy

The relevant environmental legislation and policy have been described in detail in Chapter 2. The EIA process, as regulated by the EIA Regulations under the NEMA (Act no. 107 of 1998) (RSA 2014), currently solely represents the legal regulations of impacts from solar power development in South Africa.

At the point where an applicant is granted with environmental authorisation, an EMPr is prepared by a competent environmental assessment practitioner (EAP) and submitted with the EIA report. The responsibility of complying with the EMPr is then with the applicant (*i.e.,* project developer) and is subject to predetermined audit intervals (RSA 2014). During the operational phase of a project, an EMS needs to be in place up until project decommissioning. In the past, this transition between EIA, EMPr and EMS has been found to be problematic in terms of carrying through important information between the different processes and the implementation of lessons learnt in a systematic manner from EIAs to EMSs. The main reasons for concern are particular areas of weakness as EMSs are not used to regulate environmental impacts by a competent authority as are EIAs (DEAT 2004a).

Different professionals are responsible for each of these sections with the overall environmental management of impacts during a project life cycle. Figure 5.1 gives an overview of where the different role players and components of the process are relevant in the project life cycle.

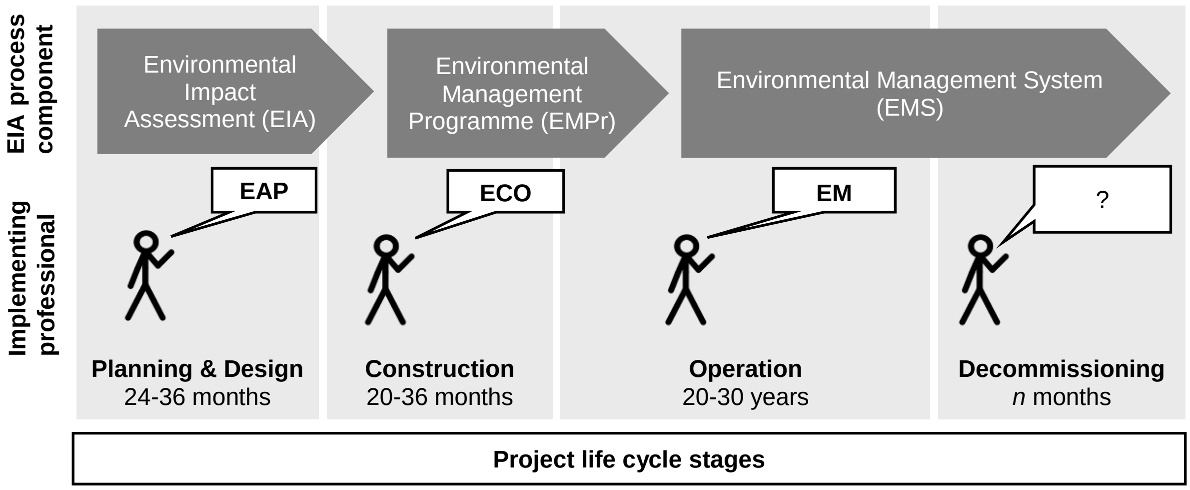


Figure 5.1 A diagram outlining the components and implementers of the EIA process as governed by the EIA Regulations during different stages of a power plant life cycle. EAP = environmental assessment practitioner, ECO = environmental control officer, EM = environmental manager. The overlap of the different EIA components into the different project life cycle stages is not to scale. No information was available about the responsible professional implementing decommissioning or the duration of this stage at the time of writing. As amended from DEAT (2004).

In addition to the EIA Regulations, BirdLife South Africa (BLSA) has published guidelines (Smith 2015) to minimise the impact of solar power facilities and infrastructure in 2015. In the guidelines, BLSA makes clear that it is supportive of solar energy generation but concerned for the potential displacement caused by solar power facilities of "*threatened, rare, endemic or range-restricted bird species*". In their guidelines, specific expected impacts on birdlife from CSP and PV facilities are given with possible mitigation measures. Although, the guidelines also propose that existing bird data is incorporated into a desktop study, followed by a site assessment and monitoring for all solar power facilities (Smith 2015). A link to the guidelines document is given in Appendix W. No other subject-specific guidelines or policy were published or available specifically for the impacts of solar power development in South Africa at the time of writing.

5.2.2. Findings-based recommendations for management and mitigation

As mentioned in the interview results in Chapter 3, feedback that was received as input for management and mitigation measures was coded and categorised under Theme 4. Apart from the suggestion that mitigation activities should be implemented by specification in the EMPr, the feedback received under this theme can broadly be categorised according to the following four topics:

1. informed site selection,
2. management of direct impacts not sufficiently covered in the EIA process,
3. adaptive management,
4. the regulation of transitions between different components of the EIA process.

These topics are discussed under the appropriate headings below and are supported by similarities from literature and/or experience from the site visits.

Informed site selection

It was mentioned throughout Chapter 3 that the impact on biodiversity from power plant development footprints could be minimised given that the spatial datasets used during the early stages of the EIA process are updated and representative of the receiving environment (*i.e.,* the baseline). The results from the interview process in combination with existing policy and regulations further highlight the importance of this early stage of environmental impact identification.

In addition to feedback that experts doubt the quality and availability of data are sufficient, seven interviewees suggested siting developments in areas with minimal habitat and biodiversity loss in order to avoid impact as a mitigation measure. To support this suggestion, an interviewee who works as an independent EAP and biodiversity specialist presented an example. The interviewee mentioned an impact assessment that was done for a wind power plant development based on desktop study alone and no ground-truthing. This impact assessment found 15 000 individual plants of an endangered plant species within the development footprint. This incident represents one case, but one has to keep in mind the risk of cumulative impacts in the event that incidents like these are repeated across the landscape. Figure 5.2 illustrates the role updated spatial biodiversity datasets could play as a pre-emptive impact mitigation measure to approve site selection in an area of ideal resources.

The feedback related to strategic planning and the coverage and implementation of the current SEA process overlap with the findings of the importance of spatial datasets. An employee from Eskom commented that the strategic environmental assessment (SEA) was done too late to identify renewable energy development zones (REDZ), which has possibly caused impacts that otherwise could have been avoided. In addition to the importance of spatial datasets, the findings indicating that several PV developments are not located within the REDZ highlight the importance of strategic tops-down management. The implementation of an effective tops-down process would ensure bi-directional communication between the competent authority, planners and developers, and the abovementioned operational weakness in the EIA process could be minimised (Bloemhof-Ruwaard et al. 1995).

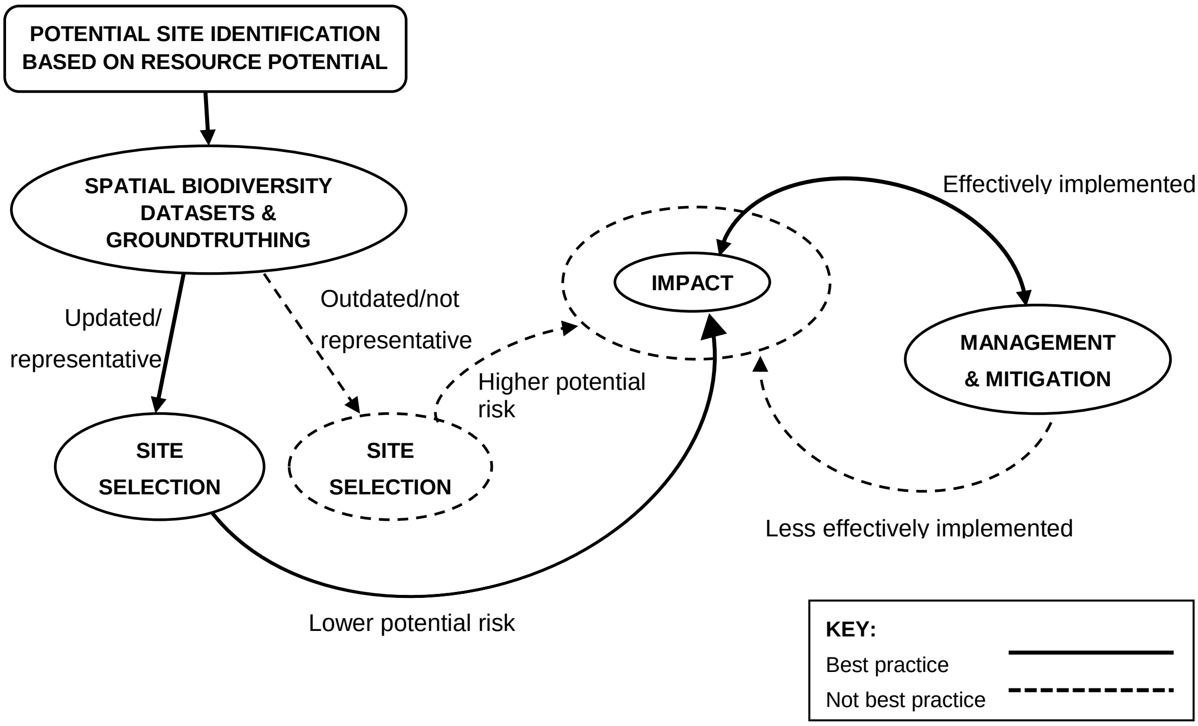


Figure 5.2 An illustration depicting the researchers view on the effect utilizing outdated spatial datasets and best practice or not best practice management. Note that the dashed 'Impact' circle is larger to indicate that impacts under non-best practice management might result in a larger or more severe impact.

Management of direct impacts not sufficiently covered in the EIA process

Topsoil removal coupled with vegetation removal was recorded as the two main impacts during construction that are not included at a satisfactory level in the EIA process. To this specific point it was learned during the site visits that lessons are shared between different developers and contractors. After experiencing excessive dust due to topsoil and vegetation removal, it is recommended to keep the vegetation and topsoil as intact as possible in the solar fields of future developments. This observation was specifically made at PV power plants, but was mentioned as a significant impact which is best avoided at Khi Solar One as well. In parabolic trough plants, the situation is a bit more challenging since topsoil and vegetation pose fire risks and the solar field area needs to be levelled and/or terraced in some instances.

The establishment of invasive alien vegetation and the impact of solar power plant infrastructure on avifauna were recorded as the primary concerning impacts during operation that are not sufficiently covered in the EIA process. Monitoring of these two impacts is recommended by the author in order to fully understand the magnitude of each impact and to apply needed mitigation measures. Such monitoring to inform EIAs have not been implemented for solar power developments as of the time of writing, but some initial steps in this direction may have begun. According to the environmental manager at Khi Solar One, an avian monitoring programme was planned to start in late 2016 at this facility (HP van Heerden 2016, personal communication, 6 June 2016).

Cumulative effects can occur due to a combination of impacts from several sources or repeated impacts from a single source. In other words, "*cumulative actions may be: incremental; aggregated; associated or connected*" (Treweek 1999; pp. 150). The feedback regarding cumulative impacts was discussed in detail in Chapters 3 and 4. Here, a recommendation is made for strategic planning and feedback between monitoring programmes. This recommendation is meant to help contain impacts by using the best available data and information to inform those who implement EIAs, EMPrs and EMSs.

The combined impact of new power lines and roads associated with solar power developments is a sub-component of cumulative impacts that are not covered in depth in this thesis. However, specific concerns related to these matters (e.g., increased roadkill and habitat fragmentation) were presented in the previous two chapters. Here, a recommendation could be made for regularly enforced speed limits and/or fines associated with roadkill incidents. Furthermore, the Endangered Wildlife Trust's African Crane Conservation Programme have done specific work in South Africa for the conservation of cranes facing the threat of collision with power lines (Endangered Wildlife Trust 2014). Perhaps future programmes could investigate which other species are affected in the areas of solar power deployment and collaborate efforts into the guidelines proposed by BLSA (Smith 2015). From a more practical perspective and pending the mortality rates in these areas, consideration for power line insulation has proved to be a successful mitigation measure for the conservation of large birds (Chevallier et al. 2015).

Adaptive management

In the context that solar power developments are still novel in South Africa, findings of adaptive management were not expected. Nevertheless, key responses from the interview process and observations during site visits put the perspective on adaptive management amongst experts in a positive light. Feedback and enthusiasm regarding lessons learnt have been received and presented in Chapter 4 from an on-the-ground professional at a solar power plant as well as a state official. Furthermore, procedural improvements during operation were mentioned by interviewees as a management suggestion, which is in essence adaptive management. A specific example of where this has proven to be successful, at least at one U.S. central receiver facility, is where heliostat aiming strategies were adapted to avoid creating 'hot spots' around the receiver when on standby, thereby minimising bird fatalities and incidents (Ho 2016).

Further practical examples from site visits include strategies to mitigate birds roosting in transformer buildings, the management of Aardvark and rodents that cause damage to buried cables, and ladders added to evaporation ponds to prohibit further drownings (Appendix J). In addition to these experiences and observations at power plants, site managers were generally quite willing to share documents related to management practices.

Regulation of the EIA process during different stages in project lifespan

The following two specific points of feedback were received regarding the transitions between different components of the EIA process throughout a project lifespan.

1. Although provisions are made within the EIA process for mitigation and management measures, experience has revealed that implementation through follow-up on the EMPr and compliance monitoring by the competent authority is rarely done. The implementation of the EMPr is thus almost entirely entrusted to the ECO, and inspections by DEA only occur in case of complaint submission. Interestingly, this finding was documented similarly more than a decade ago about the EIA process in the United Kingdom by Marshall (2002). Site visits presented contrasting evidence from the Kaxu and Xina parabolic trough plants. At these two sites, ECOs initiated a revision to storm water

management plans, which form part of the EMPr, to aid in rehabilitating the topsoil which had been removed from the solar field.

2. Apart from the administrative implementation of EIAs, the hand-over from EAPs to ECOs when implementing EMPrs were regarded as problematic by an environmental manager with experience as an EAP and ECO. It was also said that the requirements for qualifications and the experience of ECOs are not clear, and this compromises the quality of ECOs. Furthermore, developers should take more responsibility to promote proactive and adaptive management amongst ECOs, but this is often lacking as there is seldom follow-through from the DEA to evaluate if the targets set within the environmental impact report were met.

Based on the areas of weakness in the 'handovers' between different responsible individuals and entities mentioned above, a first recommendation is that an independent third party coordinator or facilitator could play a valuable role to ensure that the necessary feedback occurs as is indicated in Figure 5.2. It is further recommended that a function be included to coordinate responsibilities and roles between EAPs, the DEA and representatives of the developer (e.g., an ECO) (Figure 5.1). Such a function also could assist in making sure that deviations from the environmental policies do not occur due to the misalignment between parties involved throughout the lifespan of a power plant.

5.3. Management and mitigation for the potential impacts of shale gas

5.3.1. Existing practice and policy

A study coordinated by the Water Resource Commission in 2014 (Esterhuyse et al. 2014) specifically highlighted the difficulty of managing impacts across various scales such as provincial boundaries and water catchment areas as one of the challenges that can be expected with shale gas development. Due to the potential impact on landscape from shale gas development, the areas of interlinkage between impacts (e.g., Krupnick et al. 2015) on the biophysical environment and impacts of a socio-economic nature are potentially plentiful as well, but they are not yet well understood. Nonetheless, monitoring of various environmental 'entities' before and during both exploration and production was a key instrument to address the multiple concerns and problems related to this unconventional oil and gas extraction. Considering this uncertainty related to shale gas development in the Karoo Basin, guidelines and internationally used mitigation measures can be used as a starting point to inform local procedures. These guidelines and measures should then be re-evaluated and fine-tuned to suit the specific conditions in the Karoo Basin before they are implemented.

At the time of writing, the only policy or legislation specifically relevant to unconventional oil or gas extraction in South Africa was the Regulations for Petroleum Exploration and Production under the Mineral and Petroleum Resources Development Act (Act no. 28 of 2002). Collectively, these regulations (hereafter, "Shale Gas Regulations") are an amendment to the Mineral and Petroleum Resources Development Regulations *"to prescribe standards and practices that must ensure the safe exploration and production of petroleum"* (DMR 2015).

The Shale Gas Regulations appear to sufficiently cover detailed activities and specifications for design of infrastructure components as well as stages of shale gas development as was investigated in this thesis (*i.e.,* with the exception of well decommissioning, which was not within the scope of this study). These regulations confirm that adherence to the EIA Regulations under the NEMA (Act no. 107 of 1998) is necessary. The regulations further contain a specific stipulation that the Council for Scientific and Industrial Research and the Council of Geoscience be registered as interested and affected parties included in the public participation component of the EIA process. A summary of the subsections within the chapters of the shale gas regulations is given in Appendix X.

5.3.2. Findings-based recommendations for management and mitigation

Due to the absence of practical shale gas experience in South Africa, it is difficult to recommend specific management practices. Nonetheless, the importance of management and mitigation was repeatedly encountered throughout literature, reports, the SEASGD draft chapters and the interview process.

Mitigation actions identified in the SEASGD

The findings of the SEASGD (Appendix O) include proposed guidelines in addition to those set out in the Shale Gas Regulations. An overview of the proposed mitigation actions coupled with the impacts and risks identified in the SEASGD are presented in Table 5.2.

The reference to the importance of monitoring in order to proactively and actively manage impacts is a consistent feature throughout all the draft chapters presented in Table 5.2. Monitoring is primarily valuable to determine the ecological baseline of the receiving environment but also to maintain or improve the effectiveness of the measures set out in management plans (Treweek 1999). Furthermore, the interviews yielded responses referring to the following topics related to management and mitigation: capacity and accountability; regulation, enforcement and incentives; baselines and monitoring. These are all discussed under the relevant headings supported by recommendations.

Table 5.2 A summary of the mitigation actions proposed per chapter in the SEASGD with the associated legislation as outlined in the SEASGD (Scholes et al. 2016).

Chapter number, topic and Chapter-specific citation	**Mitigation actions**	**Topic specific legislation**
3: Air quality and GHG emissions (Winkler et al. 2016)	• Flaring and venting reduction • Emission control technologies • Monitor and measure fugitive emissions	NEMA: Air Quality Act (Act no. 34 of 2004)
4: Earthquakes (Durrheim et al. 2016)	• Seismic monitoring • Disaster insurance • Train and equip emergency responders	-
5: Water resources (Hobbs et al. 2016)	• Surface linings, intermediate well casings and fluid containment on well pads • Constant surface and sub-surface data collection and installation of permanent monitoring equipment • Use fracturing fluid that is less harmful to the environment; recycling and reusing wastewater • Radioactive element tracing • Test fracturing before full fracturing per well • Establish baselines, avoid ecologically sensitive sites, continuous monitoring	NEMA (Act no. 107 of 1998) National Water Act (Act no. 36 of 1998) Water Services Act (Act no. 108 of 1997)
6: Impacts on Waste Planning and Management (Oelofse et al. 2016)	• Design sites to minimise construction and maintenance risk • Contain waste products on site • Design proper liquid transfer pipelines • Informed site selection for waste disposal sites • Prohibit deep well injection • Develop standards and norms for flowback and produced water before this water is discharged to surface water bodies or used for land application • Minimise spills by using best practice	NEMA (Act no. 107 of 1998) NEMA: Waste Act (Act no. 56 of 2008) National Water Act (Act no. 36 of 1998) National Nuclear Regulator Act (Act no. 47 of 1999) National Road Traffic Act (Act no. 93 of 1996) Disaster Management Act (Act no. 57 of 2002)
7: Biodiversity and Ecological impacts: Landscape processes, ecosystems and species (Holness et al. 2016)	• Avoid ecologically sensitive areas • Concentrate rather than distribute shale gas development activities (e.g., clustering well pads) • Rehabilitate vegetation after production • Road networks must be standardised and existing roads used as far as possible with limited disturbance when new roads are constructed • Prohibit any activities outside demarcated work areas and <50 m from wetlands or water courses • Monitor construction material to be free from alien species and practice alien species clearing throughout development • Erosion control • Enforce speed limits and prohibit off-road driving • Establish fences or corridors to guide the movement of fauna over or off roads	NEMA (Act no. 107 of 1998) NEMA: Biodiversity Act (Act no. 10 of 2004) NEMA: Protected Areas Act (Act no. 57 of 2003) National Water Act (Act no. 36 of 1998)

Capacity and accountability

At least three interviewees explicitly voiced their concerns for the lack of administrative and political capacity to handle management and answer questions of accountability to environmental risks and accidents. Distrust and anticipation of corruption were also mentioned on this topic. While a number of such comments were recorded, it should be noted that these are concerns related to the feedback on direct impacts and were not unexpected.

Krupnick et al. (2015) study the priorities of environmental risk pathways associated with shale gas development to different stakeholder groups in the U.S. by means of structured interview surveys. In addition to the question of priorities of various risk pathways, they also asked respondents if they think sufficient research has been done on the various risk pathways. An average of 70.7% of the respondents indicated that they think enough research has been done, and 29.3% said that more information is needed. Amongst the different stakeholder groups (*i.e.,* non-government organizations, industry, academics and government), academics indicated the largest need for more research and industry representatives indicated the smallest. Furthermore, respondents were asked whether they think government or industry should take responsibility for managing risk pathways. From the response across all stakeholder groups, 73.9% were in favour of the government taking responsibility, and 26.1% were in favour of industry taking responsibility. Interestingly, industry indicated the highest percentage (34.5%) of favour towards industry taking responsibility.

The results from the study presented above indicate that different expert groups have different interests that are likely coupled to mandates and/or agendas. It is exactly this possible conflict of interest and mismatch of agendas that could create opposing forces, making recommendations for accountability a very challenging task. Perhaps a third party regulator, which has equal board representation from relevant and involved interest groups, would be best suited to ensure competent capacity and proper implementation of regulations throughout the shale gas development stages.

Regulation, enforcement and incentives

The Shale Gas Regulations (DMR 2015) appear to cover all findings in this investigation regarding the regulation activities that form part of shale gas exploration and production. In addition to the legislation and guidelines relevant to each chapter of the SEASGD, as presented in Table 5.2, the draft chapters present recommendations and referrals to existing guidelines. From this body of legislation, policies and practical mitigation guidelines, it becomes apparent that the legislative support to address the impacts associated with shale gas development might largely be in place. However, related to concern of sufficient human skills and capacity, the concern for compliance and effective implementation of these regulations will represent the efficacy of this regulatory framework. Unfortunately, a track record which lacks policy implementation in South Africa does not alleviate this concern (Rossouw & Wiseman 2004). A separate point of feedback was received in which an interviewee commented that the current EIA process is not adequate to address the impacts of shale gas development and that it should be customised. This concern, however, remains unaddressed as the Shale Gas Regulations do not refer to possible adaptions being made to the current EIA.

Feedback was given regarding the need to follow-up regulations with the appropriate enforcement. This feedback was supported by recommendations from interviewees that incentives and penalties could be used to leverage compliance and motivate developers towards technology interventions that ensure lower impact. Findings from Henriques and Sadorsky (1996) suggest that environmental regulation is a lesser motivator to a firm’s environmental responsibilities than the pressure from shareholders, customers and community members. Therefore, motivation to increase environmental compliance in shale gas prospectors might need to be considered outside the environmental governance framework (Lemos & Agrawal 2006).

With respect to the potential complexity of effective environmental governance (Lemos & Agrawal 2006), making recommendations to aid in the effective regulation and enforcement of mitigation practices is not a menial task. The primary recommendation here is similar to the recommendation made for third-party regulation of the EIA process for solar power development to drive the agenda for EIA towards possessing a substantive purpose (Cashmore 2004). The Department of Mineral Resources is designated be the competent authority for EIAs on shale gas development (DMR 2015), whereas the DEA is the designated competent authority for all other EIAs. This inconsistency and shift of responsibility could be of some concern, considering the highlighted unknowns related to shale gas development and the various potential impacts associated with an emerging development activity. Thus the contribution from an independent third party to ensure compliance and monitoring throughout the project life cycle, and interacting with those stakeholders shown in Figure 5.1, should be valuable and useful to coordinate feedback between impacts and regulations.

Baselines and monitoring

Interview feedback regarding the quality of spatial datasets used to determine baseline conditions were discussed in Chapter 4. This feedback is relevant, considering that determining the baseline condition of the receiving environment is part of the ‘scoping’ phase in the EIA process (RSA 2014) and that a known baseline is needed to monitor deviations that could occur due to impacts (Treweek 1999).

The unknown nature of baseline conditions in areas of shale gas development in the U.S. is documented as a central concern because it makes measuring deviations from such baselines (possibly due to shale gas activities) very challenging (Brantley et al. 2014). In this light, an interviewee who is a shale gas researcher at a South African university regards being able to establish baseline conditions prior to shale gas development as a unique opportunity. He said, “*we have a global duty to do this, there is no other area in the world that is in the same position than what we are currently in.*” This individual further suggested that the nature of impacts will be determined by regulations which are formed based on the baseline conditions. This suggestion, again, stresses the importance of baseline conditions. Therefore, the value of using best available information and spatial data in the EIA process and the role it plays in minimising impacts in important habitats (Figure 5.2) (Shene-Verdoorn & Ncube 2014) is very high, and establishing baseline datasets is a key recommendation.

Milt et al. (2016) analyse trade-offs of shale gas impacts in forest areas in Pennsylvania. The analysis is based on optimizing the location of well pads in relation to the location of supportive infrastructure such as water sources, pipelines and roads or limiting the location of well pads to only previously disturbed areas. Results indicated that environmental impact interactions are predominantly synergistic whereby the avoidance of an impact is likely to be related to the avoidance of another. Supported by these results, a final recommendation here is that known baseline conditions of the Karoo environment should be used in combination with areas of highest shale gas resource potential to determine where infrastructure placement will have the least significant combined impact.

5.4. Conclusion

Management and mitigation measures in current environmental legislation and regulations appear to cover a wide spectrum of impacts throughout the lifetime of developments. The management of novel impacts from emerging energy developments does, however, need additional attention as experience and knowledge of energy technologies and the associated impacts increase.

Considering the feedback from interviews that biodiversity data for the arid biomes are particularly scarce or patchy, the use of scientific or academic enquiry such as this thesis to inform management has additional value. Implementation and compliance to policy and guidelines, which are updated based on monitoring data, is the crux. To manage and minimise the risk of cumulative impacts of energy developments, a tops-down approach is needed that contributes towards strategic planning, integration between different project-specific EIAs and ensures the effectiveness of feedback loops. A neutral referee will be able to play a valuable role here in coordinating roles and responsibilities between the different development stages of both solar power and shale gas developments.

CHAPTER 6: CONCLUSION

This thesis offers a number of findings and recommendations from the investigation on the environmental impact of solar power and shale gas development in two arid biomes of South Africa. This chapter summarises the key findings, contributions, final conclusions and recommendations for future work.

6.1. Summary of findings

The findings for both solar power and shale gas are summarised firstly regarding the direct footprint of developments and then at a landscape scale, which considers the upscaling of energy developments into the future. Finally, a few pertinent points about the EIA and SEA processes are made as playing key roles in the containment of the impacts as identified at footprint- and landscape levels.

Several direct environmental impacts at the individual solar power plant level have been identified and investigated. Of these, interviewees indicated that landscape impact such as habitat fragmentation and transformation and the impact on fauna were the most prominent concerns. The impacts of solar flux around central receivers and bird collision with PV panels or heliostats were specifically highlighted as being specifically relevant to the two solar power technologies. Impacts similar to those mentioned throughout the interview process were observed during the site visits as well. The site visits provided evidence that these power plant-level impacts are being managed as guided by EMPrs and EMSs, and this represents positive evidence for adaptive management in situ. Lastly, it was found that the impacts during the construction stage, which represents approximately 10% of a power plant lifespan, is the most significant.

The current spatial footprint associated with solar power plants was found to be relatively low, and even at an increase of approximately 80% in capacity to the two solar power technologies, the projected affected area within the Nama-Karoo and Savanna biomes remains low (~1.8% combined). Regardless of these findings, however, the landscape impact associated with the increase in support infrastructure such as roads and powerlines (*i.e.,* the 'lollipop effect'), which contributes to impacts outside the power plant footprint, could present an alternative view on the significance of landscape impacts associated with deployment in the arid biomes. Additionally, specific care will be needed regarding the proximity and location of Important Bird Areas relative to new solar power developments.

Shale gas development appears to pose a significant risk on water resource quality and quantity, and this is the primary concern. The secondary concern involves habitat fragmentation in the context of largely absent baseline conditions. The risk associated with the impact on water resources is accentuated by several unknowns such as the source of water for hydraulic fracturing, already stressed water resources in the arid Karoo environment, limited information on deep groundwater resources and U.S. experience of non-disclosure about the composition of fracturing fluid. Pending the economic viability of the shale gas resource, these impacts are expected to be minimal during exploration, but these impacts are expected to increase significantly in severity and geographical distribution during the production stage after wellfields have been established.

In order to adequately assess the anticipated impact of shale gas development on biodiversity, it is critical to establish baseline conditions of the actual areas within the large exploration applications area in which exploration and production will occur. Other environmental impacts such as that on air quality and waste creation are expected to increase irrespective of the specific location of these reduced prospective areas. Regardless of the baseline conditions, the cumulative impacts associated with the number of- and widespread impacts of shale gas development are a major concern. Combined with longer-term landscape dynamics, such cumulative impacts present several unknown effects and potential consequences. These impacts are furthermore expected to escalate during the production stage, and the concern for the legacy after well-closure is recognised.

Environmental planning and authorization based on updated spatial biodiversity datasets is an early bottom-up management action whereby prevention involves keeping energy development footprints outside of high-risk ecological areas. The management of impacts through use of the current South African environmental policy is seemingly sufficient for solar power if properly implemented through the different stages of a solar power plant lifespan. The EIA process for shale gas development would need to be customised and rigorously implemented to minimise the risk of the suite of possible impacts.

For both solar power and shale gas, impact monitoring data should feed back into management protocols and be integrated with strategic planning. Such an integrated approach is key to ensure relevant practice and contained impacts from energy developments in the receiving environment. The recommendation for a neutral third-party referee to manage roles and responsibilities across different development stages would play an important role in such integration. In the long-term, such strategic management would then also account for other land uses and impacting factors in arid biomes such as climate change.

The principle of the current SEA process is a positive start to strategic planning, but it is not legally binding. The low percentage of PV power plants located in the SEA-identified zones puts the usefulness of the SEA into question. However, more concrete linkages between EIAs guided by areas identified through SEAs could provide a next step to legal assessment of the cumulative impacts.

6.2. Final conclusions

Solar power developments are increasing in the Nama-Karoo and Savanna biomes, and shale gas development activities could potentially commence in the Karoo Basin as well as increase drastically within the next few years. These biomes essentially transition from being hosts to transmission lines to becoming the sources from which energy is distributed to a large fraction of South Africa or beyond. Understanding how to measure the impacts associated with the energy developments remains vital to ensure the conservation of natural resources whilst making progress towards a more diverse energy system.

CSP and PV have similar impacts at power plant level, but each presents technology-specific challenges. Pending the collection and analysis of impact monitoring data, the impacts from individual solar power plants are diverse and widespread, but they appear to be low risk within the respective receiving environments. These impacts are seemingly containable if planning is done for location and resources such as the water needs for CSP. These plans should be completed in an integrated, strategic manner and supported with management throughout the entire project lifespan.

For shale gas development, the suite of possible impacts is understood, but there are too many unknown factors to conclude on the severity and further effects of these impacts in the Karoo environment. Application of the precautionary principle is strongly advised in context of the uncertainty related to shale gas development and the lack of baseline conditions. Ideally, information about the baseline conditions would help to avoid possible impacts and contribute to a better understanding of conservation planning in the study area.

The current EIA process' coverage seems to be generally sufficient for the impacts at power plant level. However, the current process is perceived to be weak in capturing cumulative impacts arising from a 'network of impacts' and is at risk where there are transitions between different development stages. The transfer of responsibility is of higher concern in the event that the Department of Mineral Resources acts as competent authority of shale gas EIAs instead of the Department of Environmental Affairs who have needed background information (e.g., EIA applications for other developments in the study area).

The objective of this thesis to understand the direct environmental impacts of solar power is considered successfully achieved. A number of primary concerns and impacts have been listed, but it is believed that monitoring data that measures change of environmental parameters in defined scopes or systems that are related to energy developmental activities will highlight specific ecological areas of concern for future research.

6.3. Contributions

Notwithstanding the lessons learnt throughout the thesis and the limitations with regards to resource availability, this thesis and the associated work made contributions to the known available information and scope of research in this field in South Africa. In addition to the main content presented in Chapters 1 through 6, supporting data and information are given as appendices.

The paper entitled '*Initial review and analysis of the direct environmental impacts of CSP in the Northern Cape, South Africa*' was published in the conference proceedings of the international SolarPACES conference of 2015 (Rudman et al. 2016b). To the best of this researcher's knowledge, this paper was the first of its kind. A second paper, '*Environmental impacts of utility-scale solar power in South Africa: A first survey of experts and stakeholders'* is in peer-review process to be published in the conference proceedings of the South Africa Solar Energy Conference of 2016 (Rudman et al. 2016a).

The mixed-method used to investigate the environmental impacts of these energy developments was a novel approach in this field of study and provides much opportunity for future refinement. The method may offer particular value due to the collection of diverse data, which combines research instruments and knowledge from various disciplines to arrive at an outcome with maximum representation of reality.

The findings of this thesis offer a first attempt to understand the impacts of solar power and shale gas in South Africa, but they also uncover a wide spectrum of possible research questions on which future enquiry can build. The interview data is a specific contribution within these findings and represents a first of its kind in South Africa at the time of writing. Sufficient data and findings warrant potential contributions towards policy. A policy brief is thus offered as Appendix Y.

Finally, this thesis was a first collaboration between the Department of Conservation Ecology and Entomology and the Department of Mechanical and Mechatronic Engineering, both at Stellenbosch University with affiliation to the Centre of Renewable and Sustainable Energy Studies. Bringing together two different disciplines in this thesis presented the author and supervisors of this study with an opportunity to integrate diverse backgrounds and increase contextual learning.

6.4. Feedback and recommendations for future research

6.4.1. Feedback on the interview form design

The interview process yielded valuable findings in the sense that it revealed information about knowledge of impacts, but it also revealed information about the experience of impact assessments. Adaption and refinement in the design of the sample size, expert group identification and in the construction of the interview form itself could increase the value of this method component. More specifically, the following suggestions, comments and general feedback were given on Section 4 of the interview form where numerical ratings were obtained.

- Suggestion: rank different biophysical elements and power plant components from highest to lowest impact severity and physical scale.
- Comment: it is not possible to rate the impacts in general, and impacts should be based on specific power plants.
- Comment: the impacts for shale gas should not be rated before they have occurred, and a risk level should rather be assigned.
- Positive feedback: well-structured interview process and compliments to the scope and motivation for the study.

One further note is that in retrospect, choosing a numerical score scale from one to five, where scoring a 'one' was intended to indicate 'no impact', might have influenced the ratings to be lower than a scenario where 'zero' represented no impact. This possible flaw in the interview form design could be seen as a measurement error (Vogt 2005).

6.4.2. Recommendations for future research

The context within which this research was conducted has much to offer; this is in terms of the study area, the diversification of the South African energy system and applicability of environmental policy and legislation in combination with planning for biodiversity and landscape conservation. An infinite number of interesting combinations of methods and scopes could be considered for future research in this context. Based on this initial investigation, the following recommendations are made:

- The interview form and sample should be refined and adapted if used in future studies.
- In order to inform integrated and strategic planning, more specific assumptions and parameters for projection on increased solar power capacity and location of infrastructure associated with shale gas development in the two study areas should be used to obtain more representative results on the future spatial footprint.
- Empirical data on the experienced direct impacts associated with solar power plants should be collected, analysed and made available to inform planning for subsequent projects and/or policy.
- Measuring the effects within ecosystems of selected impacts at power plant level (*i.e.*, asking research questions specific to different ecological parameters) could give context specific insights to the impacts

of energy developments. Two such examples are to extend the investigation to other biomes or to study the effects and the creation of barriers in ecosystems.

- The mixed-method ultimately contributed to richer, complimentary findings and could be valuable if expanded to studies that include non-direct environmental impacts and/or socio-ecological findings related to other alternative energy developments in the Nama-Karoo and Savanna biomes.
- Future studies on shale gas development in the Karoo are encouraged to consult the chapter by Todd et al. (2016) in the book titled: "*Hydraulic fracturing in the Karoo: Critical legal and environmental perspectives".* This book was not yet published at the time of this thesis' completion.

REFERENCES

Abdallah, S., 2004. The effect of using sun tracking systems on the voltage–current characteristics and power generation of flat plate photovoltaics. Energy Conversion and Management, 45(11), pp.1671–1679.

Abengoa, 2016. KaXu Solar One. Available at: http://www.abengoa.com/web/en/novedades/kaxu/acerca_kaxu/ [Accessed September 12, 2016].

Addinsoft, 2015. XLSTAT 2015 Help documentation. Available at: http://assistly-production.s3.amazonaws.com/211808/kb_article_attachments/71753/xlstat_help_EN_original.pdf?AWSAccessKeyId=AKIAJNSFWOZ6ZS23BMKQ&Expires=1474008646&Signature=DKBh6gCFVUESRwHY+JYVySua/h4=&response-content-disposition=filename="xlst.

Adeel, Z., 2005. Ecosystems and human well-being: desertification synthesis, Washington: World Resources Institute.

Akella, A.K., Saini, R.P. & Sharma, M.P., 2009. Social, economical and environmental impacts of renewable energy systems. Renewable Energy, 34(2), pp.390–396. Available at: http://dx.doi.org/10.1016/j.renene.2008.05.002.

Alberta Energy Regulator, 2011. ERCB Investigation Report: Caltex Energy Inc., hydraulic fracturing incident, 16-27-068-10W6M, Available at: http://www.aer.ca/data-and-publications/publications/ongoing-investigations.

Alberta Energy Regulator, 2012. Midway Energy Ltd. hydraulic fracturing incident: interwellbore communication, Available at: http://www.aer.ca/data-and-publications/publications/ongoing-investigaions.

Andrews, A., 1990. Fragmentation of Habitat by Roads and Utility Corridors: A Review. Australian Zoologist, 26(3).

Anon, 2016. Oxford English Dictionary. Available at: http://www.oed.com/view/Entry/92036?rskey=6VTgf1&result=1#eid.

Arthur, J.D., Coughlin, B.J. & Bohm, B.K., 2010. Summary of Environmental Issues, Mitigation Strategies, and Regulatory Challenges Associated With Shale Gas Development in the United States and Applicability to Development and Operations in Canada. In Canadian Unconventional Resources and International Petroleum Conference. Society of Petroleum Engineers.

Atkinson, D. et al., 2016. Chapter 11: Impacts on Social Fabric Second Order Draft for Stakeholder Comment, Available at: http://seasgd.csir.co.za/wp-content/uploads/2016/06/13_Shale-Gas-Assessment_SOD_Ch-11_Social.pdf.

Babbie, E., 2010. The Practice of Social Research, Twelfth Edition, Belmont, CA.

Baker, L., Newell, P. & Phillips, J., 2014. The Political Economy of Energy Transitions: The Case of South Africa. New Political Economy, 19(6), pp.1–28. Available at: http://www.tandfonline.com/doi/abs/10.1080/13563467.2013.849674.

Banks, D. & Schaffler, J., 2006. The potential contribution of renewable energy in South Africa, Cape Town. Available at: http://earthlife.org.za/www/wp-content/uploads/2009/04/potential-of-re-in-sa-feb06.pdf.

Barua, M. et al., 2011. Defining Flagship Uses is Critical for Flagship Selection: A Critique of the IUCN Climate Change Flagship Fleet. AMBIO, 40(4), pp.431–435. Available at: http://dx.doi.org/10.1007/s13280-010-0116-2.

Bekhechi, M. & Mercier, J., 2002. The legal and regulatory framework for environmental impact assessments : a study of selected countries in Sub-Saharan Africa, Available at: http://documents.worldbank.org/curated/en/573451468002164226/The-legal-and-regulatory-framework-for-environmental-impact-assessments-a-study-of-selected-countries-in-Sub-Saharan-Africa;jsessionid=3jCVKFJXJBBk3adsy21Ks7+5.

Bergesen, J.D. et al., 2014. Supplementary materials: Thin-Film Photovoltaic Power Generation Offers Decreasing Greenhouse Gas Emissions and Increasing Environmental Co-benefits in the Long Term. Environmental science & technology, 48(16), pp.9834–43. Available at: http://www.ncbi.nlm.nih.gov/pubmed/24984196.

Beukes, P., Cowling, R. & Higgins, S., 2002. An ecological economic simulation model of a non-selective grazing system in the Nama Karoo, South Africa. Ecological Economics, 42(1), pp.221–242.

Bevanger, K., 1998. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biological Conservation, 86(1), pp.67–76.

BirdLife South Africa (BLSA), 2015. Important Bird Areas. Available at: http://www.birdlife.org.za/conservation/important-bird-areas.

Bloemhof-Ruwaard, J.M. et al., 1995. Interactions between operational research and environmental management. European Journal of Operational Research, 85(2), pp.229–243.

Bole-Rentel, T., 2015. Climate and Energy Shale Gas 101 : Introduction to Water Impacts, Available at: http://awsassets.wwf.org.za/downloads/wwf_shale_gas_report.pdf.

Bourne, A. et al., 2016. A Socio-Ecological Approach for Identifying and Contextualising Spatial Ecosystem-Based Adaptation Priorities at the Sub-National Level. Plos One, 11(5), p.e0155235. Available at: http://dx.plos.org/10.1371/journal.pone.0155235.

Boyer, C. et al., 2011. Shale Gas : A Global Resource. Oilfield Review, 23, pp.28–39.

Boyle, G., 2012a. Renewable Energy Third. G. Boyle, ed., Oxford University Press.

Boyle, G., 2012b. Solar photovoltaics. In G. Boyle, ed. Renewable Energy Power for a Sustainable Future. Oxford University Press, pp. 75–115.

Bracken, N. et al., 2015. Concentrating Solar Power and Water Issues in the U. S. Southwest, Available at: http://www.nrel.gov/docs/fy15osti/61376.pdf.

Branosky, E., Stevens, A. & Forbes, S., 2012. Defining the Shale Gas Life Cycle: A Framework for Identifying and Mitigating Environmental Impacts. World Resources Institute, (October), pp.1–12. Available at: http://www.wri.org/publication/shale-gas-life-cycle-framework-for-impacts.

Brantley, S.L. et al., 2014. Water resource impacts during unconventional shale gas development: The Pennsylvania experience. International Journal of Coal Geology, 126(November 2013), pp.140–156. Available at: http://dx.doi.org/10.1016/j.coal.2013.12.017.

Bridge, G. et al., 2013. Geographies of energy transition: Space, place and the low-carbon economy. Energy Policy, 53, pp.331–340. Available at: http://dx.doi.org/10.1016/j.enpol.2012.10.066.

British Pretoleum (BP), 2015. Statistical Review of World Energy 2015, Available at: http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf.

Brittingham, M.C. et al., 2014. Ecological Risks of Shale Oil and Gas Development to Wildlife, Aquatic Resources and their Habitats. Environmental science & technology, 48(September 2014), pp.11034–11047. Available at: http://www.ncbi.nlm.nih.gov/pubmed/25188826.

Brundtland, G. et al., 1987. Our Common Future ('Brundtland report'), Oxford University Press, USA. Available at: http://www.bne-portal.de/fileadmin/unesco/de/Downloads/Hintergrundmaterial_international/Brundtlandbericht.File.pdf?linklisted=2812.

Bryman, A., 2015. Social Research Methods 5th ed., Oxford: Oxford University Press.

Burkhardt, J.J. 3rd, Heath, G.A. & Turchi, C.S., 2011. Life cycle assessment of a parabolic trough concentrating solar power plant and the impacts of key design alternatives. Environmental science & technology, 45(6), pp.2457–2464.

Buskirk, T., 2008. Significance Level. In P. Lavrakas, ed. Encyclopaedia of survey research methods. SAGE Publications. Available at: http://methods.sagepub.com.ez.sun.ac.za/reference/encyclopedia-of-survey-research-methods/n532.xml.

Caboz, J., 2016. The Fracking Future Fades. Forbes Africa, pp.44–46. Available at: http://www.cimera.co.za/images/FA-2016Ju-racking(3).pdf.

Carr, L.W., Fahrig, L. & Pope, S.E., 2002. Impacts of Landscape Transformation by Roads. In K. J. Gutzwiller, ed. Applying Landscape Ecology in Biological Conservation. New York, pp. 225–243.

Cashmore, M., 2004. The role of science in environmental impact assessment: process and procedure versus purpose in the development of theory. Environmental Impact Assessment Review, 24(4), pp.403–426.

Chapman, G., Wait, R. & Kleynhans, E., 2015. The governance of shale gas production in South Africa. South African Journal of International Affairs, 461(August), pp.1–20. Available at: http://dx.doi.org/10.1080/10220461.2015.1096211.

Chevallier, C. et al., 2015. Retrofitting of power lines effectively reduces mortality by electrocution in large birds: An example with the endangered Bonelli's eagle. Journal of Applied Ecology, 52(6), pp.1465–1473.

Chevallier, L. & Woodford, A., 1999. Morpho-tectonics and mechanism of emplacement of the dolerite rings and sills of the western Karoo, South Africa. South African Journal of Geology, 102(1), pp.43–54. Available at: http://sajg.geoscienceworld.org/content/102/1/43.

Chinanelli, R., Kretschmer, X. & Holditch, S., 2012. Petroleum and natural gas. In D. Ginley & D. Cahen, eds. Fundamentals of Materials for Energy and Environmental Sustainability. Cambridge University Press, pp. 106–117.

CIMERA, 2014. KARIN explores the Karoo stratigraphy. Centre of Excellence for Integrated Mineral and Energy Resource Analysis. Available at: http://www.cimera.co.za/index.php/latest-news/item/karin-explores-the-karoo-and-its-fossil-energy-resources [Accessed August 15, 2016].

Clark, W.C. & Dickson, N.M., 2003. Sustainability science: the emerging research program. Proceedings of the National Academy of Sciences of the United States of America, 100(14), pp.8059–61. Available at: http://www.pnas.org/cgi/content/long/100/14/8059 [Accessed June 25, 2015].

Clarke, C., 2013. Bird Deaths Mount at Ivanpah Solar. KCET, Online. Available at: https://www.kcet.org/redefine/bird-deaths-mount-at-ivanpah-solar.

Clarke, C., 2015. Scores of Birds Killed During Test of Solar Project in Nevada. KCET, Online. Available at: https://www.kcet.org/redefine/scores-of-birds-killed-during-test-of-solar-project-in-nevada.

Coffin, A.W., 2007. From roadkill to road ecology : A review of the ecological effects of roads. Journal of Transport Geography, 15, pp.396–406.

Cohen, B. & Winkler, H., 2014. Greenhouse gas emissions from shale gas and coal for electricity generation in South Africa. South African Journal of Science, 110(3), pp.2–6.

Cohen, L. & Holliday, M., 1996. Design 5. In Practical Statistics for Students. SAGE Publications. Available at: http://methods.sagepub.com.ez.sun.ac.za/Book/practical-statistics-for-students/n16.xml.

Corona, B. & San Miguel, G., 2015. Environmental analysis of a Concentrated Solar Power (CSP) plant hybridised with different fossil and renewable fuels. Fuel, 145, pp.63–69.

Council for Geosciences, 2015. Karoo Basin Map. Available at: http://karoospace.co.za/dolerite-karoos-fracking-game-changer/.

Council for Scientific and Industrial Research (CSIR), 2013a. DEA National Strategic Environmental Assessment for the efficient and effective rollout of wind and solar photovoltaic energy. Available at: http://www.csir.co.za/nationalwindsolarsea/background.html.

Council for Scientific and Industrial Research (CSIR), 2016a. Scientific Assessment of Shale Gas Development SUMMARY DOCUMENT, Available at: http://seasgd.csir.co.za/wp-content/uploads/2016/05/Final_SA_Summary-Doc_10May15.pdf.

Council for Scientific and Industrial Research (CSIR), 2016b. Shale Gas Development in the Central Karoo : A Scientific Assessment of the Positive and Negative Consequences SUMMARY FOR POLICY MAKERS, Available at: http://seasgd.csir.co.za/wp-content/uploads/2016/06/2_Shale-Gas-Assessment_SOD_SPM.pdf.

Council for Scientific and Industrial Research (CSIR), 2015a. Strategic Environmental Assessment for Electricity Grid Infrastructure. Available at: https://egi.csir.co.za/ [Accessed August 2, 2016].

Council for Scientific and Industrial Research (CSIR), 2015b. Strategic Environmental Assessment for Shale Gas Development in South Africa: Background Information Document. Available at: Available at: http://seasgd.csir.co.za/wp-content/uploads/2015/10/Shale-Gas-SEA-BID_Sep2015_ELECTRONIC-CIRCULATION_21092015LQ.pdf.

Council for Scientific and Industrial Research (CSIR), 2014a. Strategic Environmental Assessment for wind and solar PV energy in South Africa - Renewable Energy Development Zones (REDZs). Available at: https://redzs.csir.co.za/.

Council for Scientific and Industrial Research (CSIR), 2015c. Strategic Environmental Assessment of the SKA Phase 1 in South Africa. Available at: http://www.skaphase1.csir.co.za/?page_id=435 [Accessed September 12, 2016].

Council for Scientific and Industrial Research (CSIR), 2013b. Strategic Water Source Areas. Available at: http://bgis.sanbi.org/SpatialDataset/Detail/504.

Council for Scientific and Industrial Research (CSIR), 2014b. The identification of suitable routing corridors for the efficient and effective expansion of Electricity Grid Infrastructure. Available at: http://biodiversityadvisor.sanbi.org/wp-content/uploads/2014/08/28-Mabin-SEABackgroundSEAMethodology.pdf.

Council of Canadian Academics, 2014. Environmental impacts of shale gas extraction in Canada, Ottawa.

Cropley, E., 2013. Insight: Water, wealth and whites - South Africa’s potent anti-fracking mix. Reuters. Available at: http://uk.reuters.com/article/uk-safrica-fracking-insight-idUKBRE99R0ER20131028.

Daily, G. ed., 1997. Nature’s Services: societal dependence on natural ecosystems, Washington D.C.: Island Press.

Dale, V.H., Efroymson, R.A. & Kline, K.L., 2011. The land use--climate change--energy nexus. Landscape Ecology, 26(6), pp.755–773. Available at: http://dx.doi.org/10.1007/s10980-011-9606-2.

Davies, R.J. et al., 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology, 56, pp.239–254. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0264817214000609.

Dean, R.J. & Milton, S.J. eds., 1999. The Karoo Ecological patterns and processes, Cambridge University Press.

Decker, J. & Marot, J., 2012. Investigation of Hydraulic Fracturing in the Karoo Basin of South Africa: Annexures,

Department of Energy (DOE), 2013a. Draft 2012 Integrated Energy Plan Update, Available at: http://www.energy.gov.za/files/IEP/IEP_Publications/Draft-2012-Integrated-Energy-Plan.pdf.

Department of Energy (DOE), 2013b. Draft Integrated Resource Plan for Electricity 2010 Update, Available at: http://www.doe-irp.co.za/content/IRP2010_updatea.pdf.

Department of Energy (DOE), 2015a. Gas to Power Programme. Independent Power Producers. Available at: https://www.ipp-gas.co.za.

Department of Energy (DOE), 2015b. Gas-to-Power programme. Available at: https://www.ipp-gas.co.za/.

Department of Energy (DOE), 2011. Integrated Resource Plan for Electricity 2010 - 2030, Available at: http://www.energy.gov.za/IRP/irp files/IRP2010_2030_Final_Report_20110325.pdf.

Department of Energy (DOE), 2016. Renewable Energy Independent Power Producer Procurement Programme. Available at: http://www.ipprenewables.co.za/ [Accessed June 11, 2016].

Department of Energy (DOE), 2015c. Renewable Energy IPP Procurement Programme (REIPPPP), Bid Window 4 Preferred Bidders Announcement. , (April), pp.1–29. Available at: http://www.ipprenewables.co.za/page/304#page/2183.

Department of Energy (DOE), 2015d. State of Renewable Energy in South Africa, Pretoria.

Department of Environmental Affairs (DEA), 2015. DEA National Landcover 2015. Available at: http://bgis.sanbi.org/SpatialDataset/Detail/496.

Department of Environmental Affairs (DEA), 2016a. Maps and graphics. Environment Geographic Information Systems (EGIS). Available at: https://www.environment.gov.za/mapsgraphics#intro [Accessed September 19, 2016].

Department of Environmental Affairs (DEA), 2016b. South African Protected Areas Database Q1 2016. Available at: http://bgis.sanbi.org/SpatialDataset.

Department of Environmental Affairs (DEA), 2016c. South African Renewable Energy EIA Application Database. Available at: http://egis.environment.gov.za/.

Department of Environmental Affairs and Tourism (DEAT), 2012. Chapter 12: South Africa. In SADC Environmental Legislation Handbook. pp. 316–371. Available at: http://www.ncbi.nlm.nih.gov/pubmed/24535957.

Department of Environmental Affairs and Tourism (DEAT), 2004a. Linking Environmental Impact Assessment & Environmental Management Systems. Available at: https://www.environment.gov.za/sites/default/files/docs/series20_linking_eia_ems.pdf.

Department of Environmental Affairs and Tourism (DEAT), 2004b. Strategic Environmental Assessment. Integrated Environmental Management Information Series, (10), pp.1–11. Available at: https://www.environment.gov.za/sites/default/files/docs/series10_strategic_environmental_assessment.pdf.

Department of Environmental Affairs and Tourism (DEAT), 1997. White Paper on the Conservation and Sustainable use of South Africa’s biological diversity, Available at: https://www.environment.gov.za/sites/default/files/legislations/biodiversity_whitepaper_18163_gen1095.pdf.

Department of Mineral Resources (DMR), 2015. Mineral and Petroleum Resources Development Act, 2002 (Act no. 28 of 2002) Regulations for Petroleum Exploration and Production, Available at: http://www.gov.za/sites/www.gov.za/files/38855_rg10444_gon466.pdf.

Department of Minerals and Energy (DME), 1998. White Paper on the Energy Policy of the Republic of South Africa, Available at: http://www.energy.gov.za/files/policies/whitepaper_energypolicy_1998.pdf.

Department of Minerals and Energy (DME), 2003. White Paper on the Renewable Energy Policy of the Republic of South Africa, Available at: https://unfccc.int/files/meetings/seminar/application/pdf/sem_sup1_south_africa.pdf.

Department of Rural Development and Land Reform (DRDLR), 2013. National Geo-Spatial Information, Datum’s and Coordinate Systems. Available at: http://www.ngi.gov.za/index.php/technical-information/geodesy-and-gps/datum-s-and-coordinate-systems [Accessed May 17, 2016].

Department of Water Affairs (DWA), 2012. Aquifer Classification of South Africa. Available at: https://www.dwa.gov.za/Groundwater/documents/Aquifer Classification.pdf.

Department of Water Affairs and Forestry (DWAF), 2004. National Water Resource Strategy, Available at: https://www.dwa.gov.za/documents/Other/Strategic Plan/NWRS2-Final-email-version.pdf.

Department of Water Affairs and Forestry (DWAF), 2012. Quaternary drainage regions data. Available at: https://www.dwa.gov.za/iwqs/gis_data/river/rivs500k.aspx.

Department of Water Affairs and Forestry (DWAF), 2006. River Catchment Data. Available at: https://www.dwa.gov.za/iwqs/gis_data/river/rivs500txt.html.

De Kock, M.O. et al., 2016. Open file progress report on exploration of the southern Karoo basin through CIMERA_KARIN borehole KZF-1 in the Tankwa Karoo, Witzenberg (Ceres) District, Available at: http://www.cimera.co.za/index.php/karin-feedback.

Desideri, U. et al., 2013. Comparative analysis of concentrating solar power and photovoltaic technologies: Technical and environmental evaluations. Applied Energy, 102, pp.765–784.

De Wit, M.J., 2011. The great shale debate in the Karoo. South African Journal of Science, 107, pp.1–9.

Dilmore, R.M. et al., 2015. Spatial and Temporal Characteristics of Historical Oil and Gas Wells in Pennsylvania: Implications for New Shale Gas Resources. Environmental science & technology, 49(20), pp.12015–23. Available at: http://dx.doi.org/10.1021/acs.est.5b00820.

Dincer, I., 1997. Energy and Environmental Impacts : Present and Future Perspectives Energy and Environmental Impacts : Present and Future Perspectives. Energy Sources, 20(February 2015), pp.427–453.

Dincer, I. & Rosen, M.A., 2013. Exergy Energy, Environment and Sustainable development Second edi., Oxford: Elsevier.

Donaldson, E., Alam, W. & Bengum, N., 2013. Hydraulic fracturing explained: Evaluation, Implementation and Challenges, Houston, Texas: Gulf Publishing Company.

Driscoll, D.L., Salib, P. & Rupert, D.J., 2007. Merging Qualitative and Quantitative Data in Mixed Methods Research : How To and Why Not. , pp.18–28.

Drohan, P.J. et al., 2012. Early Trends in Landcover Change and Forest Fragmentation Due to Shale-Gas Development in Pennsylvania: A Potential Outcome for the Northcentral Appalachians. Environmental Management, 49(5), pp.1061–1075. Available at: http://dx.doi.org/10.1007/s00267-012-9841-6.

Durrheim, R., Doucoure, M. & Midzi, V., 2016. Earthquakes. In R. Scholes et al., eds. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks. Pretoria. Available at: http://seasgd.csir.co.za/individual-chapter-pdfs/.

Dwernychuk, L. & Boag, D., 1972. Ducks nesting in association with gulls - an ecological trap? Canadian Journal of Zoology, 50(5), pp.559–563.

Eberhard, A., Kolker, J. & Leigland, J., 2014. South Africa's Renewable Energy IPP Procurement Program: Success Factors and Lessons, Washington DC. Available at: http://www.ee.co.za/article/south-africas-reippp-programme-success-factors-lessons.html.

Egoh, B. et al., 2009. Spatial congruence between biodiversity and ecosystem services in South Africa. Biological Conservation, 142(3), pp.553–562. Available at: http://www.sciencedirect.com/science/article/pii/S0006320708004436.

Ehtiwesh, I.A.S., Coelho, M.C. & Sousa, A.C.M., 2016. Exergetic and environmental life cycle assessment analysis of concentrated solar power plants. Renewable and Sustainable Energy Reviews, 56, pp.145–155.

Ek, K., 2005. Public and private attitudes towards "green" electricity: the case of Swedish wind power. Energy Policy, 33(13), pp.1677–1689.

Endangered Wildlife Trust, 2014. African Crane Conservation Programme. Available at: https://www.ewt.org.za/accp/powerlines.html [Accessed September 28, 2016].

Eskom, 2011. COP17 Fact sheet: Eskom generation plant mix. Available at: http://www.eskom.co.za/OurCompany/SustainableDevelopment/ClimateChangeCOP17/Documents/GenerationMix.pdf.

Esterhuyse, S. et al., 2014. Development of an Interactive Vulnerability Map and Monitoring Framework to Assess the Potential Environmental Impact of Unconventional Oil and Gas Extraction by Means of Hydraulic Fracturing, Available at: http://www.wrc.org.za/Knowledge Hub Documents/Research Reports/2149-1-14.pdf.

Everett, B., 2012. Solar Thermal Energy. In G. Boyle, ed. Renewable Energy Power for a Sustainable Future. Oxford: Oxford University Press, pp. 21–74.

Fahrenbruch, A.L. & Bube, R.H., 1983. Fundamentals of solar cells, Photovoltaic Solar Energy Conversion, Academic Press. Available at: https://books.google.co.za/books?hl=en&lr=&id=eh7H-9cz-IoC&oi=fnd&pg=PP1&dq=history+and+description+of+photovoltaic+power&ots=wi48igd1MA&sig=iAZJSUwDQHpy61dbU05mZarJXgc#v=onepage&q&f=false.

Fairley, P., 2015. Solar Towers Don't Seem to Be the Bird Destroyers Once Thought. IEEE SPECTRUM, p.Online. Available at: http://spectrum.ieee.org/energywise/green-tech/solar.

Falkner, R., 2014. Global environmental politics and energy: Mapping the research agenda. Energy Research and Social Science, 1, pp.188–197. Available at: http://dx.doi.org/10.1016/j.erss.2014.03.008.

Ferrar, K.J. et al., 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. International Journal of Occupational and Environmental Health, 19(2), pp.104–112. Available at: http://dx.doi.org/10.1179/2049396713Y.0000000024.

Fichardt, M., 2014. Gas Utilisation Master Plan. Available at: http://www.fossilfuel.co.za/conferences/2014/GAS-SA-2014/Session-1/02Michael-Fichardt.pdf.

Fluri, T.P., 2009. The potential of concentrating solar power in South Africa. Energy Policy, 37(12), pp.5075–5080. Available at: http://dx.doi.org/10.1016/j.enpol.2009.07.017.

Foden, W. et al., 2007. A changing climate is eroding the geographical range of the Namib Desert tree Aloe through population declines and dispersal lags. Diversity and Distributions, 13(5), pp.645–653. Available at: http://dx.doi.org/10.1111/j.1472-4642.2007.00391.x.

Food and Agriculture Organization (FAO), 1999. Land Use. Available at: http://www.fao.org/nr/land/use/en/ [Accessed June 30, 2016].

Fourie, D., 2015. Falcon Oil & Gas Limited Petroleum Exploration Right – Environmental Management Programme : Seismic Survey, Southern Karoo Basin Petroleum Exploration Right – Environmental Management Programme : Seismic Survey, Southern Karoo Basin, Available at: http://www.srk.co.za/sites/default/files/File/South-Africa/publicDocuments1/Falcon_Seismic_EMPr/424473_Falcon_Seismic_EMPr_27February2015.pdf.

Friese, S., 2014. ATLAS. ti 7 User Guide and Reference. , pp.1–469. Available at: https://www.researchgate.net/publication/264158353_ATLASti_7_User_guide_and_reference.

Fthenakis, V. & Kim, H.C., 2009. Land use and electricity generation: A life-cycle analysis. Renewable and Sustainable Energy Reviews, 13(6–7), pp.1465–1474.

Fthenakis, V. & Kim, H.C., 2010. Life-cycle uses of water in U.S. electricity generation. Renewable and Sustainable Energy Reviews, 14(7), pp.2039–2048.

Geel, C. et al., 2013. Shale Gas Characteristics of Permian Black Shales in South Africa: Results from Recent Drilling in the Ecca Group (Eastern Cape). Energy Procedia, 40, pp.256–265. Available at: http://linkinghub.elsevier.com/retrieve/pii/S187661021301624X [Accessed August 16, 2016].

GeoModel Solar, 2014. Accuracy-Enhanced Solar Maps of South Africa with Technical report prepared for Centre of Renewable and Sustainable Energy Studies, Stellenbosch University.

Gibbs, G., 2007. Thematic coding and categorizing. In Qualitative Research kit: Analyzing qualitative data. London, Enland: SAGE Publications, pp. 28–55. Available at: http://methods.sagepub.com/book/analyzing-qualitative-data/n4.xml.

Golder Associates, 2015. Bundu Gas and Oil Exploration (Pty) Ltd: Updated Environmental Management Programme Report in support of application for Petroleum Exploration Rights within the Magisterial Districts of Somerset East, Cradock, Pearston and Jansenville, Eastern Cape Provin, Available at: http://www.golder.com/af/modules.php?name=Pages&sp_id=1793.

Golder Associates, 2013. Preliminary Site Selection Report ; Desktop Identification of Areas Within which Exploration Sites Could be Positioned, Available at: http://www.golder.com/bw/en/modules.php?name=Documents&op=viewlive&sp_id=3240.

Grobbelaar, S., Researcher, S. & Gauché, P., 2014. Developing a competitive concentrating solar power industry in South Africa : Current gaps and recommended next steps, (July), pp.37–41. Available at: http://dx.doi.org/10.1080/0376835X.2014.891971.

Gulati, M. et al., 2013. The Water–energy–food Security Nexus: Challenges and Opportunities for Food Security in South Africa. Aquatic Procedia, 1, pp.150–164. Available at: http://www.sciencedirect.com/science/article/pii/S2214241X1300014X [Accessed May 7, 2015].

Guo, D. et al., 2016. Conservation of Quiver Trees in Namibia and South Africa under a Changing Climate. Journal of Geoscience and Environmental Protection, 4, pp.1–8. Available at: http://file.scirp.org/pdf/GEP_2016072213430435.pdf.

Gwet, K.L., 2008. Computing inter-rater reliability and its variance in the presence of high agreement. The British journal of mathematical and statistical psychology, 61(Pt 1), pp.29–48. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18482474 [Accessed December 2, 2016].

Hanke, W. et al., 2014. The impact of livestock grazing on plant diversity: An analysis across dryland ecosystems and scales in southern Africa. Ecological Applications, 24(5), pp.1188–1203.

Hedden, S., Moyer, J.D. & Rettig, J., 2013. Fracking for Shale Gas in South Africa: Blessing or Curse? Institute for Security Studies, (9), pp.1–12. Available at: http://www.issafrica.org/uploads/AF9_6December2013.pdf.

Henriques, I. & Sadorsky, P., 1996. The Determinants of an Environmentally Responsive Firm: An Empirical Approach. Journal of Environmental Economics and Management, 30(3), pp.381–395.

Hernandez, R. et al., 2015. Solar energy development impacts on land cover change and protected areas. Proceedings of the National Academy of Sciences of the United States of America, 112(44), pp.13579–84. Available at: http://www.pnas.org/cgi/content/long/112/44/13579 [Accessed May 1, 2016].

Hernandez, R.R. et al., 2014. Environmental impacts of utility-scale solar energy. Renewable and Sustainable Energy Reviews, 29, pp.766–779. Available at: http://dx.doi.org/10.1016/j.rser.2013.08.041.

Hernandez, R.R., Hoffacker, M.K. & Field, C.B., 2015. Efficient use of land to meet sustainable energy needs. Nature Climate Change, (March), pp.1–6. Available at: http://www.nature.com/doifinder/10.1038/nclimate2556.

Hernandez, R.R., Hoffacker, M.K. & Field, C.B., 2014. Land-Use Efficiency of Big Solar. Environmental Science & Technology, 48, pp.1315–1323.

Ho, C.K., 2016. Review of Avian Mortality Studies at Concentrating Solar Power Plants. In AIP Conference Proceedings. AIP Publishing.

Hobbs, P. et al., 2016. Water Resources. In R. Scholes et al., eds. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks. Pretoria: Council of Scientific and Industrial Research. Available at: http://seasgd.csir.co.za/individual-chapter-pdfs/.

Hoffman, T. & Ashwell, A., 2001. Land degradation in South Africa, Cape Town: University of Cape Town.

Hoffmann, W.A., Schroeder, W. & Jackson, R.B., 2002. Positive feedbacks of fire, climate, and vegetation and the conversion of tropical savannah. Geophysical Research Letters, 29 (22), p.9.1-9.4.

Holloway, M.D. & Rudd, O., 2013. Fracking: the operations and environmental consequences of hydraulic fracturing, John Wiley & Sons.

Holness, S. et al., 2016. Biodiversity and Ecological Impacts : Landscape Processes, Ecosystems and Species. In R. Scholes et al., eds. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks. Pretoria. Available at: http://seasgd.csir.co.za/individual-chapter-pdfs/.

Horner, R.M. & Clark, C.E., 2013. Characterizing variability and reducing uncertainty in estimates of solar land use energy intensity. Renewable and Sustainable Energy Reviews, 23, pp.129–137.

Hosenuzzaman, M. et al., 2015. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. Renewable and Sustainable Energy Reviews, 41, pp.284–297.

Howarth, R.W., Santoro, R. & Ingraffea, A., 2011. Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic Change, 106, pp.679–690.

Hugget, R.J., 1993. Modelling the human impact on nature, Oxford University Press.

Ingegnoli, V., 2002. Landscape Transformation and Pathology. In Landscape Ecology: A Widening Foundation. Springer-Verlag New York, pp. 119–145.

Ingle, M. & Atkinson, D., 2015. Can the circle be squared? An enquiry into shale gas mining in South Africa’s Karoo. Development Southern Africa, 32(5), pp.539–554. Available at: http://www.tandfonline.com/doi/full/10.1080/0376835X.2015.1044076.

International Energy Agency (IEA), 1998. Benign energy? The environmental implications of renewables. Organization for Economic Co-operation and Development.

International Energy Agency (IEA), 2012. Golden Rules for a Golden Age of Gas. World Energy Outlook Special Report on Unconventional Gas, p.150. Available at: http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/weo2012_goldenrulesreport.pdf.

International Energy Agency (IEA), 2013. Resources to Reserves 2013 - Oil, Gas and Coal Technologies for the Energy Markets of the Future. , p.272.

International Energy Agency (IEA), 2014. Technology Roadmap Solar Photovoltaic Energy. Available at: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf.

International Renewable Energy Agency (IRENA), 2012. Working paper: Solar Photovoltaics. Available at: https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf.

Jack, S. et al., 2016. Climate change sentinel or false prophet? The case of Aloe dichotoma. *Diversity and Distributions*, 22(7), pp.745–757.

Janss, G.F.E., 2000. Avian mortality from power lines: a morphologic approach of a species-specific mortality. Biological Conservation, 95(3), pp.353–359.

Jenner, S. & Lamadrid, A.J., 2013. Shale gas vs coal : Policy implications from environmental impact comparisons of shale gas, conventional gas, and coal on air, water, and land in the United States. Energy Policy, 53, pp.442–453. Available at: http://dx.doi.org/10.1016/j.enpol.2012.11.010.

Jerolmack, C. & Khan, S., 2014. Talk Is Cheap: Ethnography and the Attitudinal Fallacy. Sociological Methods & Research, 43(2), pp.178–209.

Joffe, H. & Yardley, L., 2004. Content and thematic analysis. In Research methods for clinical and health psychology. Thousand Oaks: SAGE, pp. 56–68.

Jordaan, W., 2009. Application of GIS in the EIA Process. Integrating Environmental Assessment into Project Development Studies, p.14. Available at: http://www.srk.co.za/files/File/newsletters/SRKnews40-Environmental_Process_letter.pdf.

Kagan, R. et al., 2014. Avian mortality at solar energy facilities in southern California: a preliminary analysis. , pp.1–28. Available at: http://alternativeenergy.procon.org/sourcefiles/avian-mortality-solar-energy-ivanpah-apr-2014.pdf.

Karlstrom, H. & Ryghaug, M., 2014. Public attitudes towards renewable energy technologies in Norway. The role of party preferences. Energy Policy, 67, pp.656–663.

Kerr, R., 2010. Natural Gas from Shale Bursts onto the Scene. Science, 328(5986), pp.1624–1626.

Kinnaman, T.C., 2011. The economic impact of shale gas extraction : A review of existing studies ☆. Ecological Economics, 70(7), pp.1243–1249. Available at: http://dx.doi.org/10.1016/j.ecolecon.2011.02.005.

Kiviat, E., 2013. Risks to biodiversity from hydraulic fracturing for natural gas in the Marcellus and Utica shales. *Annals of the New York Academy of Sciences*, 1286(1), pp. 1-14.

Klein, S.J.W., 2013. Multi-Criteria Decision Analysis of Concentrated Solar Power with Thermal Energy Storage and Dry Cooling.

Klein, S.J.W. & Rubin, E.S., 2013. Life cycle assessment of greenhouse gas emissions, water and land use for concentrated solar power plants with different energy backup systems. Energy Policy, 63, pp.935–950. Available at: http://dx.doi.org/10.1016/j.enpol.2013.08.057.

Klöpffer, W., 1997. Life cycle assessment. Environmental Science and Pollution Research, 4(4), pp.223–228. Available at: http://dx.doi.org/10.1007/BF02986351.

Klug, H., 2010. The Constitution of South Africa, Portland Oregon: Hart Publishing.

Kraemer, S., 2015. One Weird Trick Prevents Bird Deaths At Solar Towers. CleanTechnica. Available at: https://cleantechnica.com/2015/04/16/one-weird-trick-prevents-bird-deaths-solar-towers/.

Kruger, T. & Jodas, K., 2010. Environmental Impact Assessment Process Final EIA Report Proposed Upington Solar Thermal Plant and Associated Infrastructure Northern Cape. Assessment, (DEA REF No: 12/12/20/1831).

Krupnick, A., Gordon, H. & Olmstead, S., 2015. Pathways to dialog: what the experts say about the environmental risks of shale gas development. Agricultural and Resource Economics Review, 2(August), pp.106–119.

Kuuskraa, V.A. et al., 2011. World Shale Gas Resources: An Initial Assessment of 14 Regions outside the United States, Washington DC. Available at: https://www.eia.gov/analysis/studies/worldshalegas/archive/2011/pdf/fullreport_2011.pdf.

Kuuskraa, V.A., Stevens, S.H. & Moodhe, K.D., 2013. Technically recoverable shale oil and shale gas resources: an assessment of 137 shale formations in 41 countries outside the United States, Washington D.C. Available at: http://www.eia.gov/analysis/studies/worldshalegas/archive/2013/pdf/fullreport_2013.pdf.

Lathan, A. & Boutin, S., 2015. Impacts of utility and other industrial linear corridors on wildlife. In R. van der Ree, D. Smith, & C. Grilo, eds. Handbook of Road Ecology. John Wiley & Sons.

Lavrakas, P., 2008. P-value. In Encyclopaedia of survey research methods. SAGE Publications. Available at: http://methods.sagepub.com.ez.sun.ac.za/reference/encyclopedia-of-survey-research-methods/n421.xml.

Lemos, M.C. & Agrawal, A., 2006. Environmental Governance. Environment and Resources, 31(1), pp.297–325.

Leung, D. & Yang, Y., 2012. Wind energy development and its environmental impact: A review. 2Renewable and Sustainable Energy Reviews, 16(1), pp.1031–1039. Available at: http://www.sciencedirect.com/science/article/pii/S1364032111004746.

Lovegrove, K. & Pye, J., 2012. Fundamental principles of concentrating solar power (CSP) systems. In Concentrating Solar Power Technology Principles, Developments and Applications. Cambridge: Woodhead Publishing Limited, pp. 16–67.

Lovegrove, K. & Stein, W., 2012. Introduction to concentrating solar power (CSP) technology. In Concentrating Solar Power Technology Principles, Developments and Applications. Cambridge: Woodhead Publishing Limited, pp. 3–15.

Lovich, J.E. & Ennen, J.R., 2011a. Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. BioScience, 61(12), pp.982–992. Available at: http://bioscience.oxfordjournals.org/cgi/doi/10.1525/bio.2011.61.12.8.

Lovich, J.E. & Ennen, J.R., 2011b. Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. BioScience, 61(12), pp.982–992.

Low, A.B. & Rebelo, A.G. Eds., 1998. Vegetation of South Africa, Lesotho and Swaziland, Second Edition, Pretoria: Department of Environmental Affairs and Tourism.

Ludwig, D., Hilborn, R. & Walters, C.J., 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science (Washington), 260(April). Available at: http://landscape.forest.wisc.edu/courses/Landscape565spr01/Ludwig_etal1993.pdf.

Lund, H., 2007. Renewable energy strategies for sustainable development. Energy, 32, pp.912–919.

Millennium Ecosystem Assessment (MA), 2005. Millennium ecosystem assessment synthesis report, Available at: http://www.klimaatportaal.nl/pro1/general/show_document_general.asp?documentid=224&GUID=%7BA338C2EF-76E7-461B-8A98-AEAB3C21E259%7D.

Mace, G.M., Norris, K. & Fitter, A.H., 2012. Biodiversity and ecosystem services: a multi-layered relationship. Trends in Ecology & Evolution, 27(1), pp.19–26.

Macknick, J. et al., 2011. A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies, Golden, Colorado. Available at: http://www.nrel.gov/docs/fy11osti/50900.pdf.

Macknick, J. et al., 2012. Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. Environmental Research Letters, 7(4), p.45802. Available at: http://stacks.iop.org/1748-9326/7/i=4/a=045802?key=crossref.6f4ebd5836ab24141e19d95fd1e65709 [Accessed June 28, 2016].

Marshall, R., 2002. Developing environmental management systems to deliver mitigation and protect the EIA process during follow up. Impact Assessment and Project Appraisal, 20(4), pp.286–292.

Masubelele, M., Hoffman, M. & Bond, W., 2015. A repeat photograph analysis of long-term vegetation change in semi-arid South Africa in response to land use and climate. Journal of Vegetation Science, 26(5), pp.1013–1023.

Mauter, M.S. et al., 2014. Regional variation in water-related impacts of shale gas development and implications for emerging international plays. Environmental Science and Technology, 48, pp.8298–8306.

Mauter, M.S. et al., 2013. The Next Frontier in United States Shale Gas and Tight Oil Extraction: Strategic Reduction of Environmental Impacts, (March), pp.1–80.

McCrary, M.D. et al., 1986. Avian Mortality at a Solar Energy Power Plant. Journal of Field Ornithology, 57(2), pp.135–141. Available at: http://www.jstor.org/stable/4513113.

McGlade, C., Speirs, J. & Sorrell, S., 2013. Unconventional gas – A review of regional and global resource estimates. Energy, 55, pp.571–584.

McKillup, S., 2006. Statistics Explained An Introductory Guide for Life Scientists, Cambridge: Cambridge University Press.

Melikoglu, M., 2014. Shale gas: Analysis of its role in the global energy market. Renewable and Sustainable Energy Reviews, 37, pp.460–468.

Midgley, G.F. & Thuiller, W., 2011. Potential responses of terrestrial biodiversity in Southern Africa to anthropogenic climate change. Regional Environmental Change, 11(1), pp.127–135. Available at: http://dx.doi.org/10.1007/s10113-010-0191-8.

Miles, R.W., Hynes, K.M. & Forbes, I., 2005. Photovoltaic solar cells: An overview of state-of-the-art cell development and environmental issues. Progress in Crystal Growth and Characterization of Materials, 51(1), pp.1–42.

Miller, A. & Lumby, B., 2012. Utility Scale Solar Power Plants, A Guide For developers and investors. Available at: https://www2.unece.org/wiki/download/attachments/25267247/SOLAR%2BGUIDE%2BBOOK.pdf?api=v2.

Mills, S.R. et al., 2012. Investigation of Hydraulic Fracturing in the Karoo Basin of South Africa, Available at: http://www.dmr.gov.za/publications/ viewdownload/182/854.html.

Milt, A.W., Gagnolet, T. & Armsworth, P.R., 2016. Synergies and Trade-offs Among Environmental Impacts under Conservation Planning of Shale Gas Surface Infrastructure. Environmental Management, 57(1), pp.21–30. Available at: "http://dx.doi.org/10.1007/s00267-015-0592-z.

Milt, A.W., Gagnolet, T.D. & Armsworth, P.R., 2016. The costs of avoiding environmental impacts from shale-gas surface infrastructure. Conservation Practice and Policy.

Milton, S.J. & Dean, W.R.J., 2015. Repairing compound damage in arid ecosystems – challenges and controversies. Transactions of the Royal Society of South Africa, 70(2), pp.127–133.

Moncrieff, G. et al., 2015. Understanding global change impacts on South African biomes using Dynamic Vegetation Models. South African Journal of Botany, 101, pp.16–23.

Mucina, L., 2006a. Nku1 Western Upper Karoo. In Vegetation of South Africa. South African National Biodiversity Institute and the Botanical Society of South Africa. Available at: http://bgis.sanbi.org/Projects/Detail/171.

Mucina, L., 2006b. Nku4 Eastern Upper Karoo. In Vegetation of South Africa. South African National Biodiversity Institute and the Botanical Society of South Africa. Available at: http://bgis.sanbi.org/Projects/Detail/171.

Mucina, L. & Rutherford, M.C. eds., 2006. The vegetation of South Africa, South African National Biodiversity Institute, Pretoria.

National Energy Technology Laboratory (NETL), 2013. Modern Shale Gas Development in the United States: An Update, Available at: https://www.netl.doe.gov/File Library/Research/Oil-Gas/shale-gas-primer-update-2013.pdf.

National Planning Commission (NPC), 2012. National Development Plan 2030, Our future - make it work, Available at: http://www.gov.za/sites/www.gov.za/files/Executive Summary-NDP 2030 - Our future - make it work.pdf.

National Renewable Energy Laboratory (NREL), 2016a. Concentrating Solar Power Projects in South Africa. Available at: http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=ZA.

National Renewable Energy Laboratory (NREL), 2016b. Concentrating Solar Power Projects in South Africa. Available at: http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=ZA [Accessed June 20, 2016].

Nature, 2009. The Shale Revolution. Nature, 460, pp.551–552.

Nel, J. et al., 2013. South Africa's Strategic Water Source Areas. , (March), p.27.

Nicot, J.-P. & Scanlon, B.R., 2012. Water use for shale gas production in Texas, U.S. Environmental Science and Technology, 46, pp.3580–3586.

Nelson Mandela Metropolitan University (NMMU), 2014. Launch of Shale Gas Project. Nelson Mandela Metropolitan University, Faculty of Science. Available at: http://science.nmmu.ac.za/News/News-Archive/2014-News/Launch-of-Shale-Gas-Project [Accessed August 15, 2016].

Northrup, J.M. & Wittemyer, G., 2013. Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecology Letters, 16(1), pp.112–125.

Noy, C., 2008. Sampling Knowledge : The Hermeneutics of Snowball Sampling in Qualitative Research Sampling Knowledge : The Hermeneutics of Snowball Sampling in Qualitative Research. International Journal of Social Research Methodology, 11(4), pp.327–344.

O'Riordan, T., 1994. Intepreting the precautionary principle, London: Earthscan.

Oelofse, S., Schoonraad, J. & Baldwin, D., 2016. Impacts on Waste Planning and Management. In R. Scholes et al., eds. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks. Pretoria: Council of Scientific and Industrial Research. Available at: http://seasgd.csir.co.za/individual-chapter-pdfs/.

Ong, S. et al., 2013. Land-Use Requirements for Solar Power Plants in the United States, Available at: http://www.nrel.gov/docs/fy13osti/56290.pdf.

Palmer, A. & Mucina, L., 2006. NKl1 Gamka Karoo Description. In Vegetation of South Africa. Available at: http://bgis.sanbi.org/Projects/Detail/171.

Panwar, N.L., Kaushik, S.C. & Kothari, S., 2011. Role of renewable energy sources in environmental protection : A review. Renewable and Sustainable Energy Reviews, 15(3), pp.1513–1524. Available at: http://dx.doi.org/10.1016/j.rser.2010.11.037.

Peck, M., 2014. Ivanpah Solar Power Tower is Burning Birds. IEEE SPECTRUM, Online. Available at: http://spectrum.ieee.org/energywise/green-tech/solar.

Perry, K. & Lee, J., 2007. Unconventional gas, Available at: http://www.npc.org/study_topic_papers/29-ttg-unconventional-gas.pdf\nfile:///C:/Users/01445593/AppData/Local/Mendeley Ltd./Mendeley Desktop/Downloaded/Holditch, Stephen A., Lee John - 2007 - Unconventional gas.pdf.

Petroleum Agency of South Africa (PASA), 2013. Explorations map. Available at: http://www.petroleumagencysa.com/index.php/maps [Accessed June 4, 2015].

Petroleum Agency of South Africa (PASA), 2014. Shale Gas Exploration Right Application areas.

Pfenninger, S. et al., 2014. Potential for concentrating solar power to provide baseload and dispatchable power. , (June), pp.4–7.

Picardi, C.A. & Masick, K.D., 2014. Research methods: designing and constructing research methods with a real-world focus, SAGE Publications.

Pollet, B.G., Staffell, I. & Adamson, K.-A., 2015. Current energy landscape in the Republic of South Africa. International Journal of Hydrogen Energy, 40(46), pp.16685–16701. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360319915024635.

Popp, D., Newell, R.G. & Jaffe, A.B., 2010. Handbook of the Economics of Innovation, Volume 2, Elsevier. Available at: http://www.sciencedirect.com/science/article/pii/S0169721810020058 [Accessed January 16, 2015].

Pretorius, I., Piketh, S.J. & Burger, R.P., 2015. The impact of the South African energy crisis on emissions. In Air Pollution XXIII. Boston: WIT Press, p. 198.

ProPublica, 2014. Hydraulic Fracturing - What is Hydraulic Fracturing? Available at: https://www.propublica.org/special/hydraulic-fracturing [Accessed July 5, 2016].

Raimondo, D. ed., 2015. South Africa's Strategy for Plant Conservation, Pretoria: South African National Biodiversity Institute and the Botanical Society of South Africa. Available at: https://www.cbd.int/doc/world/za/za-nbsap-oth-en.pdf.

Ravi, S., Lobell, D.B. & Field, C.B., 2014. Trade-offs and synergies between biofuel production and large solar infrastructure in deserts. Environmental Science and Technology, 48(5), pp.3021–3030.

Republic of South Africa (RSA), 2012. Baseload IPP Procurement Programme 2012 Determination under section 32(1) of the Electricity Regulation Act 4 of 2006. Government Gazette. Available at: http://www.gov.za/sites/www.gov.za/files/36005_gon1075.pdf.

Republic of South Africa (RSA), 1996a. Constitution of South Africa (Act. No. 108 of 1996), Available at: http://www.gov.za/sites/www.gov.za/files/images/a108-96.pdf.

Republic of South Africa (RSA), 1996b. Constitution of the Republic of South Africa. , 230(38), pp.1–107. Available at: http://www.gov.za/documents/constitution/1996/a108-96.pdf.

Republic of South Africa (RSA), 2008. National Energy Act (Act no. 34 of 2008), Available at: http://www.energy.gov.za/files/policies/NationalEnergyAct_34of2008.pdf.

Republic of South Africa (RSA), 2014. National Environmental Management Act, 1998 (Act no. 107 of 1998) Environmental Impact Assessment Regulations, 2014 (R. 982), Available at: http://www.greengazette.co.za/pages/national-gazette-37230-of-17-january-2014-vol-583_20140117-GGN-37230-003.

Republic of South Africa (RSA), 1998. National Environmental Management Act (Act no. 107 of 1998), Available at: https://www.environment.gov.za/sites/default/files/legislations/nema_amendment_act107.pdf.

Republic of South Africa (RSA), 2015. South Africa's Intended Nationally Determined Contribution. Available at: http://www4.unfccc.int/submissions/INDC/Published Documents/South Africa/1/South Africa.pdf [Accessed May 13, 2016].

Reyers, B. et al., 2007. Developing products for conservation decision-making: Lessons from a spatial biodiversity assessment for South Africa. Diversity and Distributions, 13(5), pp.608–619.

Reyers, B. et al., 2009. Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society, 14(1), p.23. Available at: http://www.ecologyandsociety.org/vol14/iss1/art38/.

Rivard, C. et al., 2014. An overview of Canadian shale gas production and environmental concerns. International Journal of Coal Geology, 126, pp.64–76.

Rockström, J. et al., 2009. Planetary boundaries: Exploring the safe operating space for humanity. Ecology and Society, 14(2).

Rossouw, N. & Wiseman, K., 2004. Learning from the implementation of environmental public policy instruments after the first ten years of democracy in South Africa. Impact Assessment and Project Appraisal, 22(2), pp.131–140.

Rowan, E.L. et al., 2011. Radium Content of Oil- and Gas-Field Produced Waters in the Northern Appalachian Basin (USA): Summary and Discussion of Data, Available at: http://pubs.usgs.gov/sir/2011/5135/pdf/sir2011-5135.pdf.

Rudman, J., Gauché, P. & Esler, K.J., 2016a. Environmental impacts of utility-scale solar power in South Africa: a first survey of experts and stakeholders. In South African Solar Energy Conference. Stellenbosch.

Rudman, J., Gauché, P. & Esler, K.J., 2016b. Initial review and analysis of the direct environmental impacts of CSP in the Northern Cape, South Africa. In p. 160015. Available at: http://scitation.aip.org/content/aip/proceeding/aipcp/10.1063/1.4949256 [Accessed November 28, 2016].

Sala, O.E. et al., 2000. Global biodiversity scenarios for the year 2100. Science (New York, N.Y.), 287(5459), pp.1770–1774.

Saldana, J., 2013. The Coding Manual for Qualitative Researchers 2nd ed., SAGE Publications.

Saldana, J., 2015. The Coding Manual for Qualitative Researchers 3rd ed. J. Seamon & J. Piper, eds., SAGE Publications.

Scarlett, L. & Boyd, J., 2015. Ecosystem services and resource management: Institutional issues, challenges, and opportunities in the public sector. Ecological Economics, 115, pp.3–10.

Scheiber-Enslin, S. et al., 2013. Integrated interpretation of potential field and seismic data in the Karoo Basin, South Africa for shale gas potential. In 13th SAGA Biennial Conference & Exhibition. SAGA. Available at: http://www.earthdoc.org/publication/publicationdetails/?publication=73040.

Schmitz, O.J., 2007. Ecology and Ecosystem Conservation, Washington DC: Island Press.

Scholes, R. et al. eds., 2016. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks, Pretoria. Available at: http://seasgd.csir.co.za/scientific-assessment-chapters/.

Scholvin, S., 2014. Journal of Southern African Studies South Africa's Energy Policy : Constrained by Nature and Path Dependency South Africa's Energy Policy : Constrained by Nature and Path Dependency. , (May), pp.37–41.

Sebitosi, A.B. & Pillay, P., 2008. Grappling with a half-hearted policy : The case of renewable energy and the environment in South Africa. , 36, pp.2513–2516.

Shene-Verdoorn, C.A. & Ncube, N., 2014. Mining and Biodiversity : Evaluating EAP standards in the sector Authors, Available at: http://awsassets.wwf.org.za/downloads/mining_report_03_sept_2014_spreads.pdf.

Smith, H., 2015. Guidelines to minimise the impact on birds of Solar Facilities and Associated Infrastructure in South Africa. BirdLife South Africa. Available at: http://www.birdlife.org.za/conservation/terrestrial-bird-conservation/birds-and-renewable-energy.

South African National Biodiversity Institute (SANBI), 2016. Biodiversity GIS. Spatial datasets. Available at: http://bgis.sanbi.org/SpatialDataset [Accessed September 19, 2016].

South African National Biodiversity Institute (SANBI), 2012. National Vegetation map of South Africa 2012. Available at: http://bgis.sanbi.org/SpatialDataset/Detail/595.

South African National Biodiversity Institute (SANBI), Savanna Biome and Nama-Karoo Biome. Available at: pza.sanbi.org/vegetation/.

South African National Parks (SANParks), 2010. National Protected Areas Expansion Strategy. Available at: http://bgis.sanbi.org/SpatialDataset.

Speight, J.G., 2013. Shale gas production processes, Oxford: Gulf Professional Publishing.

Spellman, F.R., 2012. Environmental Impacts of Hydraulic Fracturing, CRC Press.

Stellenbosch University, 2016. Helio100. Available at: http://helio100.sun.ac.za/ [Accessed September 12, 2016].

Stern, D., Common, M. & Barbier, E., 1996. Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. World Development, 24(7), pp.1151–1160. Available at: http://www.sciencedirect.com/science/article/pii/0305750X96000320.

Stevens, S., 1946. On the Theory of Scales of Measurement. Science, 103(2684), pp.677–680. Available at: http://www.mpopa.ro/statistica_licenta/Stevens_Measurement.pdf.

Steyl, G., van Tonder, G.J. & Chevallier, L., 2012. State of the art: Fracking for shale gas exploration in South-Africa and the impact, Available at: http://www.wrc.org.za/Knowledge Hub Documents/Research Reports/KV 294-11.pdf.

Svensen, H. et al., 2007. Hydrothermal venting of greenhouse gases triggering Early Jurassic global warming,

Teske, S. et al., 2016. Solar Thermal Electricity Global Outlook 2016, Available at: http://www.solarpaces.org/press-room/news/item/98-new-solar-thermal-electricity-report.

The Royal Society & Royal Academy of Engineering, 2012. Shale gas extraction in the UK : a review of hydraulic fracturing, London.

Therivel, R., 2012. Strategic environmental assessment in action, Second Edition, Routledge.

Thompson, S., Treweek, J. & Thurling, D., 1997. The Ecological Component of Environmental Impact Assessment: A Critical Review of British Environmental Statements. Journal of Environmental Planning and Management, 40(2), pp.157–171.

Van Tonder, G., 2012. Karoo Groundwater Atlas Vol 1, Cape Town. Available at: http://s05.static-shell.com/content/dam/shell/static/zaf/downloads/media/karoo-groundwateratlas.pdf.

Todd, S. et al., 2016. The potential impacts of fracking on biodiversity of the Karoo Basin. In J. Glazewski & S. Esterhuyse, eds. *Hydraulic fracturing in the Karoo: Critical legal and environmental perspectives*. Juta, pp. 190–213.

Treweek, J., 1999. ECOLOGICAL IMPACT ASSESSMENT, Bodmin: Blackwell Science Ltd.

Treweek, J., 1995. Ecological Impact Assessment. Impact Assessment, 13(3), pp.289–315. Available at: http://www.tandfonline.com/doi/abs/10.1080/07349165.1995.9726099.

Treweek, J., 1996. Ecology and environmental impact assessment. Journal of Applied Ecology, 33(2), pp.191–199.

Tsantopoulos, G., Arabatzis, G. & Tampakis, S., 2014. Public attitudes towards photovoltaic developments: Case study from Greece. Energy Policy, 71, pp.91–106.

Tsoutsos, T., Frantzeskaki, N. & Gekas, V., 2005. Environmental impacts from the solar energy technologies. Energy Policy, 33(3), pp.289–296.

Turney, D. & Fthenakis, V., 2011. Environmental impacts from the installation and operation of large-scale solar power plants. Renewable and Sustainable Energy Reviews, 15(6), pp.3261–3270. Available at: http://dx.doi.org/10.1016/j.rser.2011.04.023.

Twidell, J. & Weir, T., 1986. Renewable energy resources, New York: EFN Spon Ltd.

U.S. Energy Information Administration (U.S. EIA), 2016. Glossary. Available at: http://www.eia.gov/tools/glossary/ [Accessed March 7, 2016].

U.S. Energy Information Administration (U.S. EIA), 2015a. South Africa: International energy data and analysis, Available at: https://www.eia.gov/beta/international/analysis_includes/countries_long/South_Africa/south_africa.pdf.

U.S. Energy Information Administration (U.S. EIA), 2015b. Technically Recoverable Shale Oil and Shale Gas Resources: South Africa, Washington DC. Available at: http://www.eia.gov/analysis/studies/worldshalegas/pdf/South_Africa_2013.pdf.

U.S. Energy Information Administration (U.S. EIA), 2015c. World Shale Resource Assessments. Assessed resource basin map. Available at: http://www.eia.gov/analysis/studies/worldshalegas/.

U.S Energy Information Administration (U.S. EIA), 2016. International Energy Outlook 2016, Available at: http://www.eia.gov/forecasts/ieo/world.cfm.

United Nations (UN), 2015. Millennium Development Goals. Millennium Development Goals. Available at: http://www.un.org/millenniumgoals/ [Accessed November 26, 2016].

United Nations (UN), 1992. United Nations Framework Convention on Climate Change. , p.25. Available at: https://unfccc.int/resource/docs/convkp/conveng.pdf.

Veldkamp, A. & Verburg, P., 2004. Modelling land use change and environmental impact. Journal of Environmental Management, 72(1), pp.1–3.

Vermeulen, P.D., 2012. A South African perspective on shale gas hydraulic fracturing. In L. and W. McCullough, ed. Internationa Mine Water Association. pp. 149–156.

Vidic, R.D. et al., 2013. Impact of shale gas development on regional water quality. Science, 340. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23687049.

Visser, E., 2016. The impact of South Africa's largest photovoltaic solar energy facility on birds in the Northern Cape, South Africa. University of Cape Town.

Vogt, P., 2005. Measurement Error. In Dictionary of statistics & methodology. SAGE Publications.

Walston, L. et al., 2015. A Review of Avian Monitoring and Mitigation Information at Existing Utility- Scale Solar Facilities, Available at: https://pdfs.semanticscholar.org/9804/a2ee6c28567014c4e4ee68f3208b530912ee.pdf.

Warner, N.R. et al., 2013. Impacts of Shale Gas Wastewater Disposal on Water Quality in Western PA.pdf. Environmental Science & Technology, 47, pp.11849–11857.

Warren, C.H., 2013. Shale gas in South Africa Toward an understanding of the security implications. African Security Review, 22(1), pp.67–73.

Wathern, P. ed., 1988. Environmental impact assessment: theory and practice, Taylor & Francis.

Weber, C.L. & Clavin, C., 2012. Life cycle carbon footprint of shale gas: review of evidence and implications. Environmental science & technology, 46, pp.5688–95. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22545623.

Wiens, J., 2002. Central Concepts and Issues of Landscape Ecology. In K. Gutzwiller, ed. Applying Landscape Ecology in Biological Conservation. New York: Springer-Verlag New York, pp. 3–21.

Wild-scholten, M.J.M. De, 2013. Author s personal copy Solar Energy Materials & Solar Cells Energy payback time and carbon footprint of commercial photovoltaic systems. Solar Energy Materials and Solar Cells, 119.

Winkler, H. et al., 2016. Air Quality and Greenhouse Gas Emissions. In R. Scholes et al., eds. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks. Pretoria. Available at: http://seasgd.csir.co.za/individual-chapter-pdfs/.

Winkler, H. & Marquand, A., 2009. Changing development paths: From an energy-intensive to low-carbon economy in South Africa. Climate and Development, 1(1), pp.47–65.

Woodford, A. et al., 2013. Karoo Groundwater Atlas Volume 2, Available at: http://gwd.org.za/sites/gwd.org.za/files/KGEG_Karoo Groundwater Atlas Volume 2_Final_12Aug13_opt_opt.pdf.

Woodford, A. & Chevallier, L., 2002. Hydrogeology of the Main Karoo Basin : Current Knowledge and Future Research Needs, Available at: http://www.wrc.org.za/Knowledge Hub Documents/Research Reports/TT179-02.pdf.

World Energy Council, 2015. 2015 Energy Trilemma Index - Benchmarking the sustainability of national energy systems, London, UK.

World Wide Fund for Nature South Africa (WWF-SA), 2015. Feasibility of the WWF Renewable Energy Vision 2030- South Africa A spatial-Temporal Analysis. , p.96.

Zou, C., 2013. Unconventional Petroleum Geology, Elsevier Inc.

APPENDICES

A. SHALE GAS RESOURCESDEFINITION AND DISTRIBUTION

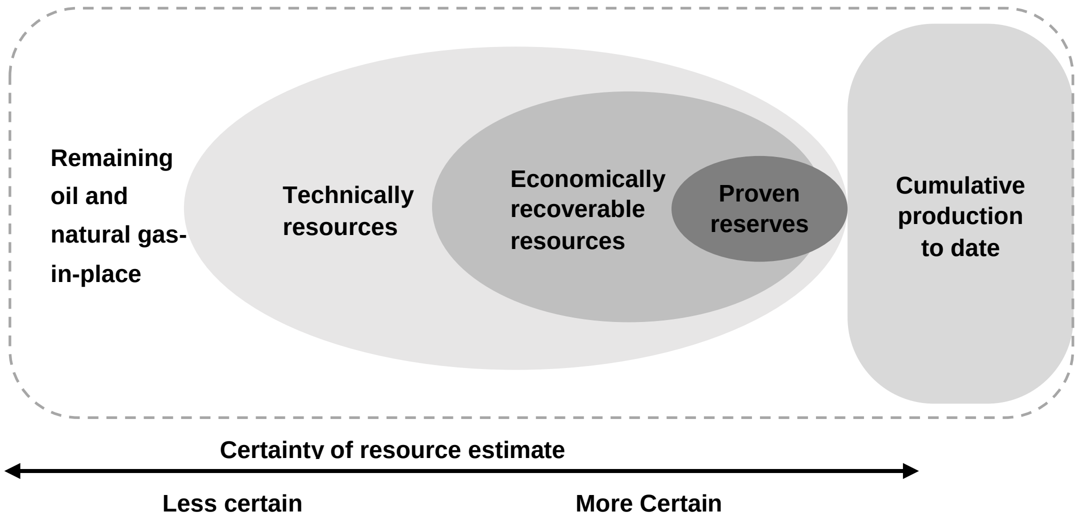


Figure A.1 A simple illustration of how oil and natural gas resources get categorised; the illustration is not to scale. As amended from US EIA (2015).

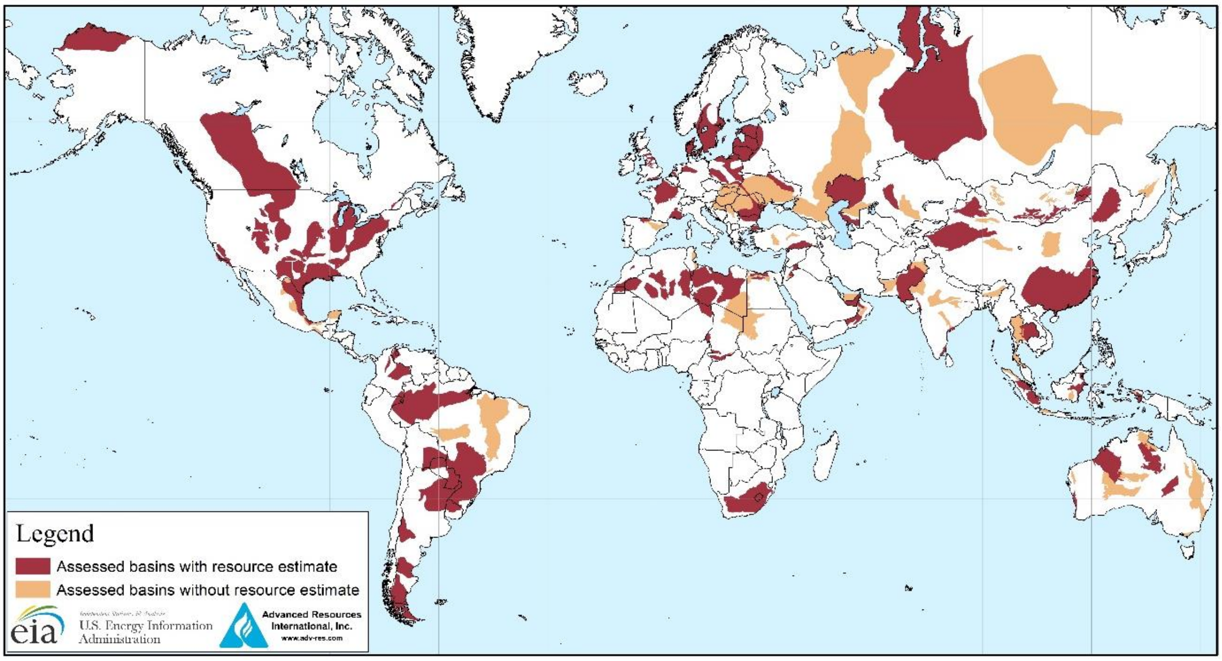


Figure A.2 A map by the U.S. Energy Information Administration showing assessed shale gas resource basins (Source: U.S. EIA 2015).

B. COMPOSITION OF FRACTURING FLUID AND FLOWBACK WATER

Table B.1 A summary of the common, known additives and compounds in fracturing fluid and flowback water.

Fracturing fluid (Vidic et al. 2013)		Flowback fluid (Steyl et al. 2012)	
Common chemical additives	**Example compounds**	**Parameter classes**	**Example compounds**
Acid	Hydrochloric acid	**Dissolved solids**	Chlorides, sulphates, calcium
Friction reducer	Polyacrylamide, petroleum distillate	**Metals**	Calcium, magnesium, barium, strontium
Corrosion inhibitor	Isopropanol, acetaldehyde	**Suspended solids**	-
Iron control	Citric acid, thioglycolic acid	**Mineral scales**	Calcium carbonate, barium sulphate
Biocide	Glutaraldehyde, 2,2-dibromo-3-nitrilopropionamide (DBNPA)	**Bacteria**	Acid producing bacteria and sulphate reducing bacteria
Gelling agent	Guar/xantham gum or hydroxyethyl cellulose	**Friction reducers**	-
Crosslinker	Borate salts	**Iron solids**	Iron oxide and iron sulphide
Breaker	Ammonium persulfate, magnesium peroxide	**Dispersed clay fines, colloids & silts**	
Oxygen scavenger	Ammonium bisulphite	**Acid gases**	Carbon dioxide, hydrogen sulphide
pH adjustment	Potassium or sodium hydroxide or carbonate		
Proppant	Silica quartz, sand		
Scale inhibitor	Ethylene glycol		
Surfactant	Ethanol, isopropyl alcohol, 2-butoxyethanol		

C. SOLAR RESOURCE MAPS

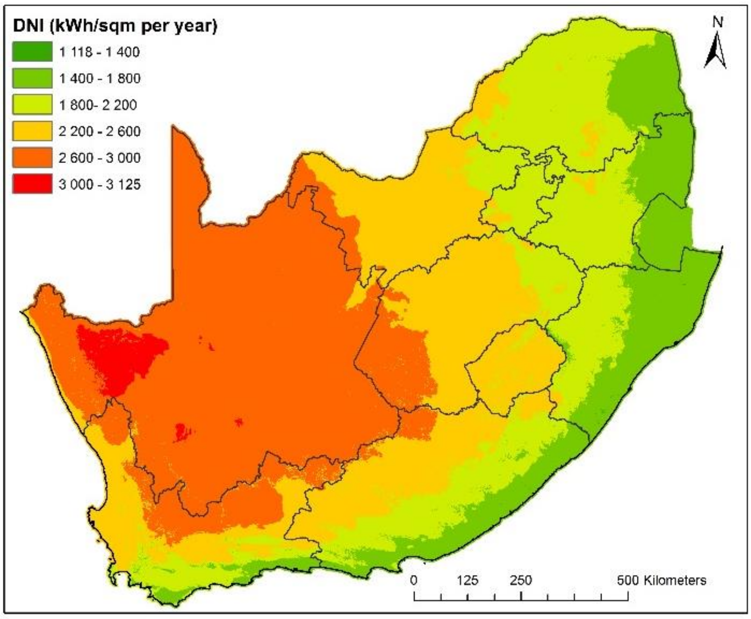


Figure C.1 A multi-year average of the annual sum Direct Normal Irradiation for SA (GeoModel Solar 2014).

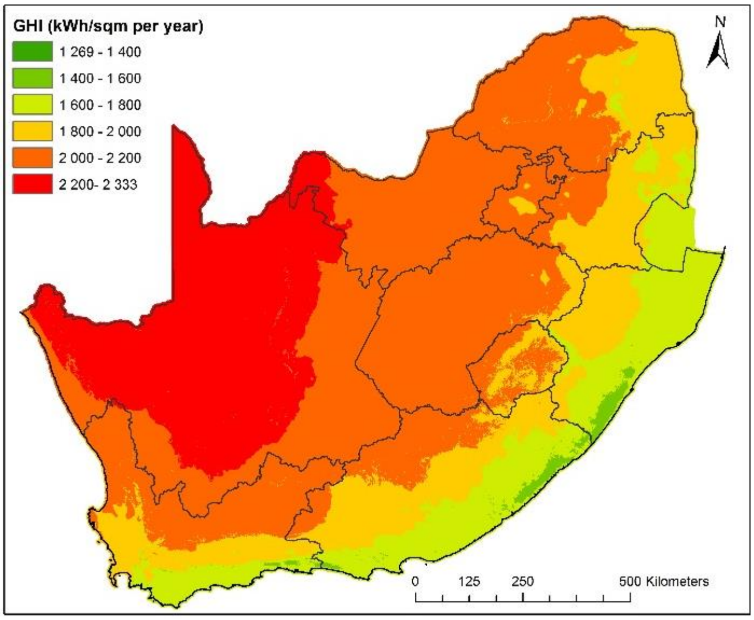


Figure C.2 A multi-year average of the annual sum Global Horizontal Irradiation for SA (GeoModel Solar 2014).

D. INTERVIEW FORM

#	Interview and personal information	
	Date:	**Location/Skype/phone:**
	Initials:	Company/Institute:
	Job title:	Qualification:
	Representing: self □ organization □	May I personally reference you? Yes □ No □
	Do you agree to participate in this interview knowing that the results of this study will be published and by only answering questions that you are confident and/or qualified and/or experienced to answer?	Yes ☐ No ☐ Comment ________________________

1	Experience information	
1.1	How long have you held your current position?	
1.2	What prior relevant positions have you held?	
1.3	What are your daily duties/responsibilities?	
1.4	Where are you predominantly based?	
1.5	What entity do you report to? (Eg. Govt agency, non-profit, contractor, educational, etc)	

Notes:
Only relevant sections need to be completed, specify if answers are applicable to CSP/PV and/or a specific project.
All questions are by default referring to SA, but for individuals elsewhere, then applicable for [________________________] place/region

2	EIA and general environmental impacts	
2.1	Do you have any experience with EIA processes in SA?	Yes ☐ No ☐ Comment________________________ ________________________________
2.2	Do you think the EIA sufficiently covers all possible impacts of the project on the natural environment?	Yes ☐ No ☐ Comment ________________________ ________________________________
2.3	Are you aware of any adverse direct impacts which solar power and/or shale gas developments have on the natural environment?	Solar power: Yes ☐ No ☐ If no, skip question 2.4.1., 4.3-4.4. Shale gas: Yes ☐ No ☐ If no, skip question 2.4.2., 4.5-4.6.
2.4.1	List impacts that you are aware of from solar power developments. 1. 2. 3. 4. 5. 6.	
2.4.2	List impacts are you aware of from shale gas developments.	

	1. 2. 3. 4. 5. 6.	
2.5	Are you aware of any of these impacts which are not covered or insufficiently covered in the EIA process? Please list.	
	Solar power	**Shale gas**
3	**EIAs and impacts related to a specific project**	
3.1	Were you involved in a specific solar power/shale gas project when the EIA was done?	Yes ☐ No ☐ How______________________________
3.2	What impacts did you observe/do you know of during **construction** which were not included in the EIA?	
3.3	What impacts did/do you observe/do you know of during **operation** which were not included in the EIA?	
3.4	What impacts do you/your supervisor regard as most significant?	
3.5	How do you manage these impacts? Also elaborate in question 5.	
3.6	Do you have an environmental management/monitoring programme/plan (EMP)?	Yes ☐ No ☐
3.7	If yes, how regularly are procedures/practices checked against the EMP?	
3.8	To your knowledge, would you say there is a need from developers for long-term monitoring of environmental impacts for this technology in SA?	Yes ☐ No ☐ Comment: ________________________
4	**Specific direct* impacts** **[Briefly explain what specific impacts means]**	
	***Direct here refers to the immediate impacts that can be observed on the physical natural environment at the relevant scale at the specified stage of development, e.g., Soil/vegetation loss due to ground preparation. Impacts such as life cycle emissions and health impacts are not regarded as direct environmental impacts here.**	
4.1	Are you familiar with/do you know the following different phases of a solar power project lifecycle: Planning ☐ Construction ☐ Operation ☐ Decommissioning ☐	Yes ☐ No ☐ Comment:________________________ _________________________________
4.2	Are you familiar with/do you know the different phases of a shale gas development: Planning ☐ Exploration ☐ Construction ☐ Operation/production ☐	Yes ☐ No ☐ Comment:________________________ _________________________________

	Decommissioning ☐	

SOLAR POWER

4.3	Please rate and comment on the impacts of CSP/PV of a <u>specific project and/or in general</u> on the following during **construction and operation**: **Is section 4.3-4.4 being completed for CSP ☐ or PV ☐?** Fill in separate forms if both experience in CSP and PV is at hand for 4.3-4.9. Please comment on species type and range where possible.

For questions 4.3 – 4.6:

- Rate impacts on a scale from 1 to 5 where 1 is none and 5 is severe
- Also rate the physical scale of each impact as follows, more than one option may also be chosen, no answer is also allowed where unsure. The radius sizes are given as guideline only:

1 - none
2 – point specific (e.g., <1km radius)
3 – local ecosystem (e.g., 1-20km radius)
4 – regional (e.g., 20-200km radius)
5 – national (across provincial boundaries)

		Severity		**Physical scale**		**Comment**
		Construction	**Operation**	**Construction**	**Operation**	
a	Soil					
b	Surface water usage					
c	Surface water quality					
d	Groundwater usage					
e	Groundwater quality					
f	Air quality					
g	Insects					
h	Birdlife					
i	Mammals					
j	Reptiles					
k	Vegetation					
l	Visual impact: glint/glare					
m	Audial impact					
n	Dust					
o						

4.4	Please rate and comment on the collective impacts of the following <u>power plant components on the surrounding natural environment</u> during **construction and operation**: Please only answer relevant to PV or CSP specifically, as indicated in 4.3.

		Severity	**Physical scale**	**Comment**

		Construction	Operation	Construction	Operation	
a	Roads					
b	Substations/power lines					
c	Waterworks					
d	Evaporation pond					
e	Power block/inverter block					
f	Solar field					
g	Energy storage facilities					
h	Offices/On-site accommodation					
i	Temporary structures/scaffolding					
j	Balance of plant					
k						

SHALE GAS

4.5 Please rate and comment on the impacts on the following during shale gas developments for the **exploration, construction and production phases,** according to your knowledge:

Please comment on species type, range and range where possible.

- Rate impacts on a scale from 1 to 5 where 1 is none and 5 is severe
- Also rate the physical scale of each impact as follows, more than one option may also be chosen, no answer is also allowed where unsure:

1 - none
2 – point specific (e.g., <1km radius)
3 – local ecosystem (e.g., 1-20km radius)
4 – regional (e.g., 20-200km radius)
5 – national (across provincial boundaries)

		Severity			**Physical scale**			**Comment**
		Exploration	Construction	Production	Exploration	Construction	Production	
a	Soil							
b	Surface water usage							
c	Surface water quality							
d	Groundwater usage							
e	Groundwater quality							
f	Air quality							
g	Insects							
h	Birdlife							

i	Mammals							
j	Reptiles							
k	Vegetation							
l	Visual impact: glint/glare							
m	Audial impact							
n	Dust							
o								

4.6	Please rate and comment on what you expect/know the collective impacts of the following components of <u>shale gas development can be on the surrounding natural environment</u> during **exploration, construction and production**:							
		Severity			**Physical scale**			**Comment**
		Exploration	**Construction**	**Production**	**Exploration**	**Construction**	**Production**	
a	Roads							
b	Gas infrastructure							
c	Well pads							
d	Subsurface drilling (vertical & horizontal)							
e	Well-casing construction							
f	Hydraulic fracturing							
g	Evaporation ponds							
h	Water recycling							
i	Waste water disposal							
j	'Frac'-fluid storage							
k	Offices/On-site accommodation							
l								

5	**Management, monitoring and mitigation (MMM) of impacts**	
5.1	Do you know of any MMM measures which can be/are implemented to minimise the impacts of CSP/PV/shale gas development/a specific project? If no, skip 5.2-5.4. If yes, mention below please.	Yes ☐ No ☐ Comment on what the MMM measures are applicable to:
	1. 2. 3.	
5.2	How often do you/other person have to implement MMM measures/actions?	Once-off ☐ Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Decadal ☐
5.3	How often do you/other person need to adapt the MMM measures/actions?	Once-off ☐ Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Decadal ☐

5.4	Are you willing to share documents containing the MMM measures/actions you implement?	Yes ☐ No ☐ Comment:
5.5	Do you know of any MMM measures which can be implemented to minimise the impacts of shale gas development? If yes, mention below please.	Yes ☐ No ☐ Comment:
	1. 2. 3.	
6	**Sources of data for baseline studies and determining impacts**	
	SOLAR POWER	
6.1	Do you know which data sets are being used for baseline studies prior to solar power developments? If yes, mention below please.	Yes ☐ No ☐ Comment:
	1. 2. 3. 4. 5.	
6.2	Do you think existing data bases in the form of field survey archives, vegetation/biodiversity maps and GIS layers are sufficient data sources in order to determine baseline conditions and predict impacts of solar power developments in SA?	Yes ☐ No ☐ Why/why not: ______________ Suggestion: _________________
6.3	Do you have any comments with regards to the data which is used for solar power EIA's?	Yes ☐ No ☐ Comment:
	SHALE GAS	
6.4	Do you know which data sets are being used for baseline studies prior to shale gas developments? If yes, mention below please.	Yes ☐ No ☐ Comment:
	1. 2. 3. 4. 5.	
6.5	Do you think existing data bases in the form of field survey archives, vegetation/biodiversity maps and GIS layers are sufficient data sources in order to determine baseline conditions and predict impacts of shale gas developments in SA?	Yes ☐ No ☐ Why/why not: __________________ Suggestion: ____________________ _______________________________
6.6	Do you have any comments with regards to the data which is used for shale gas EIA's?	Yes ☐ No ☐ Comment: ___________________ ______________________________
7	**Summary/Open ended**	
7.1	Do you have any other comments w.r.t the impacts of solar power on the natural environment?	

7.2	Do you have any other comments w.r.t the impacts of shale gas on the natural environment?
8	**Any questions or recommendations for this interview**
9	**Would you like to recommend anyone for this interview?**
Name: ________________________ Email address: ________________________ Name: ________________________ Email address: ________________________ Name: ________________________ Email address: ________________________	

E. SITE VISIT DESCRIPTIONS

Table E.1 A summary of the descriptive information for solar developments visited during the field trip conducted during June 2016. This information supports the sites indicated in Figure 3.3 in Chapter 3.

Name (Site visit number): Power rating and technology type	**REIPPPP round: Development phase**	**Closest town, [vegetation type (s)], size and previous land use**	**Comment**
Touws River (1): 44 MW Concentrated Photovoltaic (CPV)	Round 1: Fully operational	Touws River [Matjiesfontein Shale Renosterveld, Western Little Karoo] 190 hectares Agricultural (crops)	This development theoretically does not fall within the boundaries of the study area, but the results of the study were included due to the positive environmental practice observed during the visit.
Linde (2): 40 MW Single-axis tracking poly-crystalline PV	Round 2: Fully operational	Hanover [Eastern Upper Karoo] 125 hectares Agricultural (sheep farm)	This development was unique in the sense that the land was still being used by the owning farmer as a camp for sheep. During the site visit sheep were seen grazing underneath and between the PV panels.
Solar Capital De Aar (3): 75 MW Fixed-tilt thin film PV	Round 1: Part operational, part in construction	De Aar [Northern Upper Karoo] 300 hectares Agricultural (sheep farm)	The owners and contractors at this plant are experiencing significant challenges with panel breakage. Development is between construction and being fully operational. Due to these challenges, rehabilitation and waste removal is lagging significantly.
Mulilo Prieska (4): 86 MW Single-axis tracking mono-crystalline PV	Round 3: End of construction	Copperton [Bushmanland Basin Shrubland] 200 hectares Agricultural (sheep farm)	With exception to ad hoc construction activities at Site 3, this was the only development still in the construction phase.
Khi Solar One (5): 50 MW Central receiver (CSP)	Round 1: Commissioning	Upington [Bushmanland Arid Grassland, Kalahari Karroid Shrubland] 300 hectares Agricultural (Cattle farm)	As the first central receiver power plant in SA, many lessons have been learnt throughout the construction and in going to the commissioning phase of this development. Both from technological and environmental perspectives, Khi Solar One is a pioneer, offering valuable input to planning and management of future central receiver power plants.
Xina Solar One (6): 100 MW Parabolic trough plant (CSP)	Round 3: Construction	Pofadder [Bushmanland Arid Grassland, Bushmandland Sandy Grassland, Eastern Gariep Plains Desert] 420 hectares Agricultural (sheep farm)	This is the neighbouring development and neighbour to another, 100 MW operational parabolic trough plant, Kaxu Solar One. It was positive to see and hear how lessons from the first development were informing practices on the second development.

F. RECORD OF CODES FOR THEME 1 OF SOLAR POWER INTERVIEW DATA

Table F.1 A summary of the codes and number of quotations per code for impact categories coded for Chapter 4 on the impact of solar power.

Impact category and code	Number of quotations
Atmospheric	
Audial impact	1
Changes in albedo	2
Impact on micro-climate	1
Risk of aerial or leachable toxic chemicals	3
Visual and dust impact	13
Biodiversity	
Biodiversity loss	2
Changes to avifauna species communities	2
Continuous impact due to traffic	1
Degradation of ecosystem services	1
Impact on aquatic biodiversity	1
Impact on endangered species	1
Impact on micro-ecosystem under panels/heliostats	2
Powerlines as responsible for much of the biodiversity impact	1
Impact on local ecology & biodiversity	10
Risk of aerial or leachable toxic chemicals	3
Risk of alien infestation	4
Fauna	
Changes to avifauna species communities	2
Evaporation ponds as attraction to species	3
Hindrance to animal movement	5
Impact of collision on avifauna by PV panels/heliostats	6
Impact on avifauna by towers	9
Impact of confusion on avifauna by PV panels	2
Impact on aquatic biodiversity	1
Impact on endangered species	1
Powerline strikes	1
Risk of alien infestation	4
Wildlife disturbance	1
Flora	
Impact on aquatic biodiversity	1

Impact on endangered species	1
Risk of alien infestation	4
Vegetation clearance	5
Water	
Diversion of water courses	6
Impact on total water resource availability	10
Risk of aerial or leachable toxic chemicals	3
Risk of toxic chemicals in PV panels	1
Landscape	
Continuous impact due to traffic	1
Diversion of water courses	6
Habitat fragmentation	5
Habitat transformation/loss	16
High land-usage for power generated	1
Land impact by associated infrastructure	4
Soil and geological impacts	
Disruption of soil profile	1
Removal/disturbance of topsoil	6
Risk of aerial or leachable toxic chemicals	3
Risk of toxic chemicals in PV panels	1

G. SUMMARY OF NUMERICAL RATINGS FROM INTERVIEWS FOR SOLAR

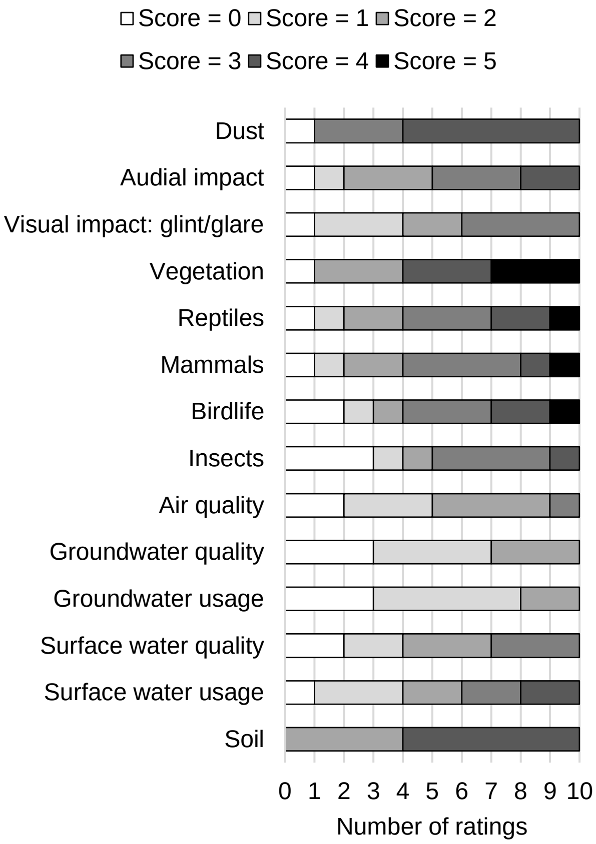


Figure G.1 Ratings for severity of impacts on different biophysical elements during CSP construction.

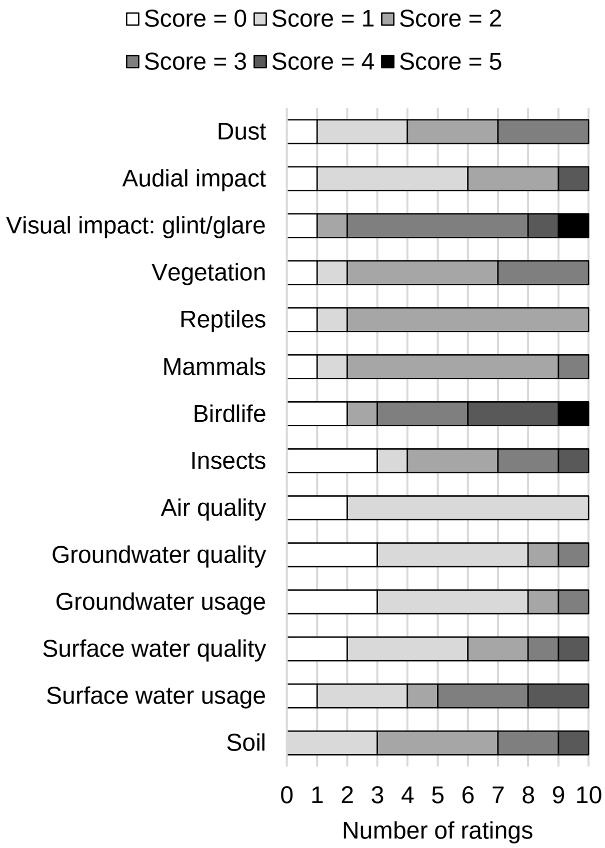


Figure G.2 Ratings for severity of impacts on different biophysical elements during CSP operation.

Table G.1 Number of ratings summarised per numerical score value for impact severity on biophysical elements during CSP construction and operation.

Biophysical elements	Number of ratings for CSP construction severity						Number of ratings for CSP operation severity					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Soil	0	0	4	0	6	0	0	3	4	2	1	0
Surface water usage	1	3	2	2	2	0	1	3	1	3	2	0
Surface water quality	2	2	3	3	0	0	2	4	2	1	1	0
Groundwater usage	3	5	2	0	0	0	3	5	1	1	0	0
Groundwater quality	3	4	3	0	0	0	3	5	1	1	0	0
Air quality	2	3	4	1	0	0	2	8	0	0	0	0
Insects	3	1	1	4	1	0	3	1	3	2	1	0
Birdlife	2	1	1	3	2	1	2	0	1	3	3	1
Mammals	1	1	2	4	1	1	1	1	7	1	0	0
Reptiles	1	1	2	3	2	1	1	1	8	0	0	0
Vegetation	1	0	3	0	3	3	1	1	5	3	0	0
Visual impact: glint/glare	1	3	2	4	0	0	1	0	1	6	1	1
Audial impact	1	1	3	3	2	0	1	5	3	0	1	0
Dust	1	0	0	3	6	0	1	3	3	3	0	0

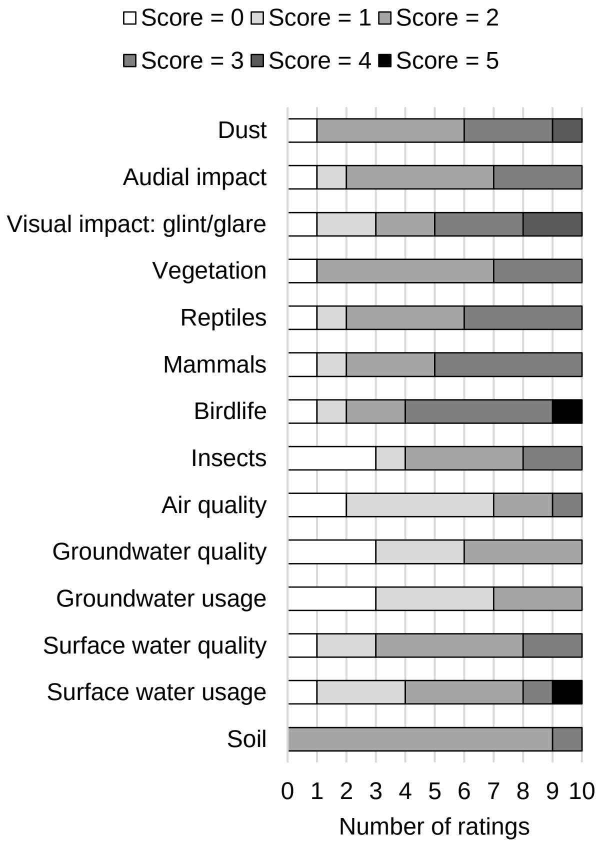


Figure G.3 Ratings for physical scale of impacts on different biophysical elements during CSP construction.

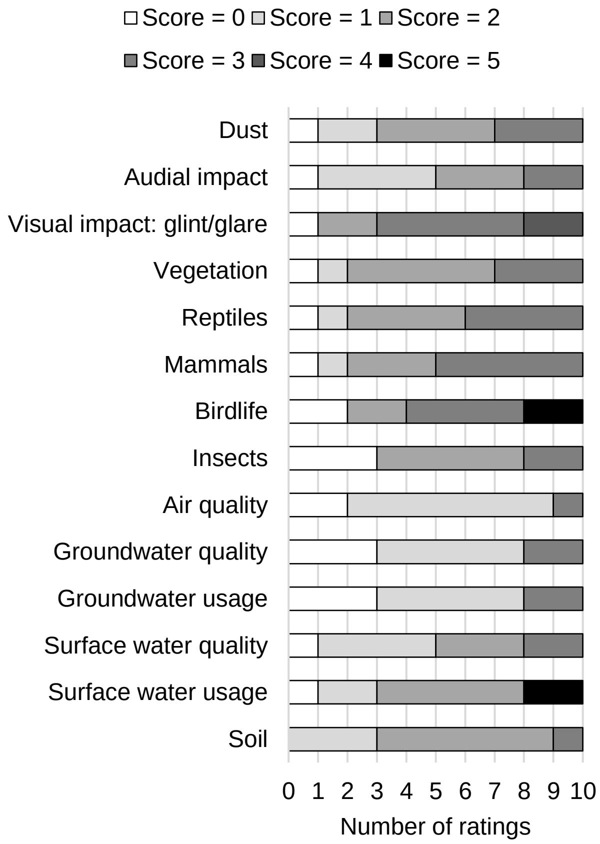


Figure G.4 Ratings for physical scale of impacts on different biophysical elements during CSP operation.

Table G.2 Number of ratings summarised per numerical score value for physical scale of impacts on biophysical elements during CSP construction and operation.

Biophysical elements	**Number of ratings for CSP construction physical scale**						**Number of ratings for CSP operation physical scale**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Soil	0	0	9	1	0	0	0	3	6	1	0	0
Surface water usage	1	3	4	1	0	1	1	2	5	0	0	2
Surface water quality	1	2	5	2	0	0	1	4	3	2	0	0
Groundwater usage	3	4	3	0	0	0	3	5	0	2	0	0
Groundwater quality	3	3	4	0	0	0	3	5	0	2	0	0
Air quality	2	5	2	1	0	0	2	7	0	1	0	0
Insects	3	1	4	2	0	0	3	0	5	2	0	0
Birdlife	1	1	2	5	0	1	2	0	2	4	0	2
Mammals	1	1	3	5	0	0	1	1	3	5	0	0
Reptiles	1	1	4	4	0	0	1	1	4	4	0	0
Vegetation	1	0	6	3	0	0	1	1	5	3	0	0
Visual impact: glint/glare	1	2	2	3	2	0	1	0	2	5	2	0
Audial impact	1	1	5	3	0	0	1	4	3	2	0	0
Dust	1	0	5	3	1	0	1	2	4	3	0	0

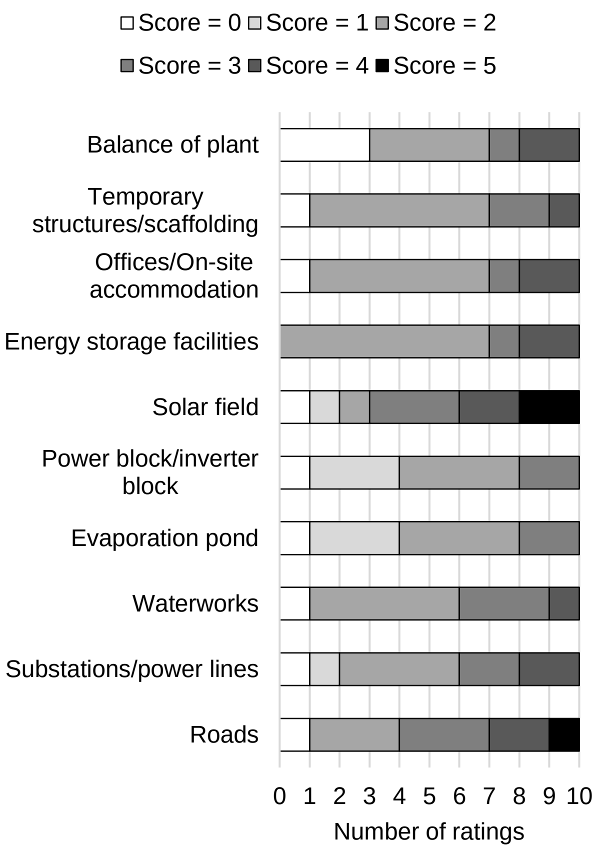


Figure G.5 Ratings for severity of impacts by different power plant components during CSP construction.

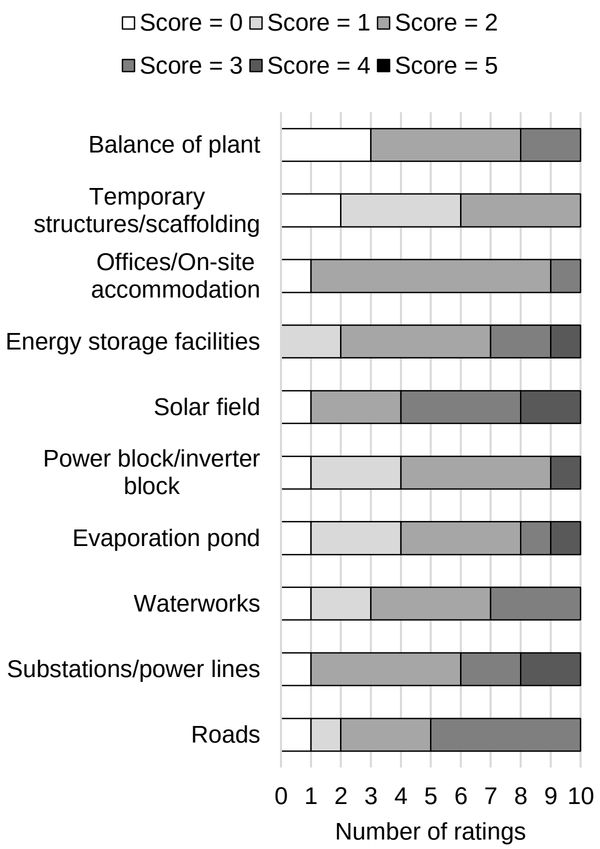


Figure G.6 Ratings for severity of impacts by different power plant components during CSP operation.

Table G.3 Number of ratings summarised per numerical score value for severity of impacts by power plant components during CSP construction and operation.

Power plant components	**Number of ratings for CSP construction severity**						**Number of ratings for CSP operation severity**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Roads	1	0	3	3	2	1	1	1	3	5	0	0
Substations/power lines	1	1	4	2	2	0	1	0	5	2	2	0
Waterworks	1	0	5	3	1	0	1	2	4	3	0	0
Evaporation pond	1	3	4	2	0	0	1	3	4	1	1	0
Power block/inverter block	1	3	4	2	0	0	1	3	5	0	1	0
Solar field	1	1	1	3	2	2	1	0	3	4	2	0
Energy storage facilities	0	0	7	1	2	0	0	2	5	2	1	0
Offices/On-site accommodation	1	0	6	1	2	0	1	0	8	1	0	0
Temporary structures/scaffolding	1	0	6	2	1	0	2	4	4	0	0	0
Balance of plant	3	0	4	1	2	0	3	0	5	2	0	0

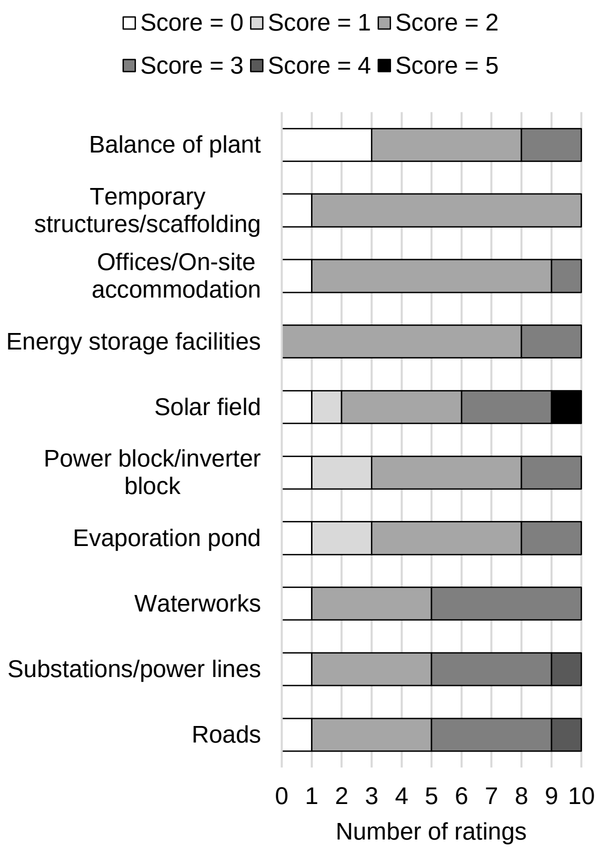


Figure G.7 Ratings for physical scale of impacts by different power plant components during CSP construction.

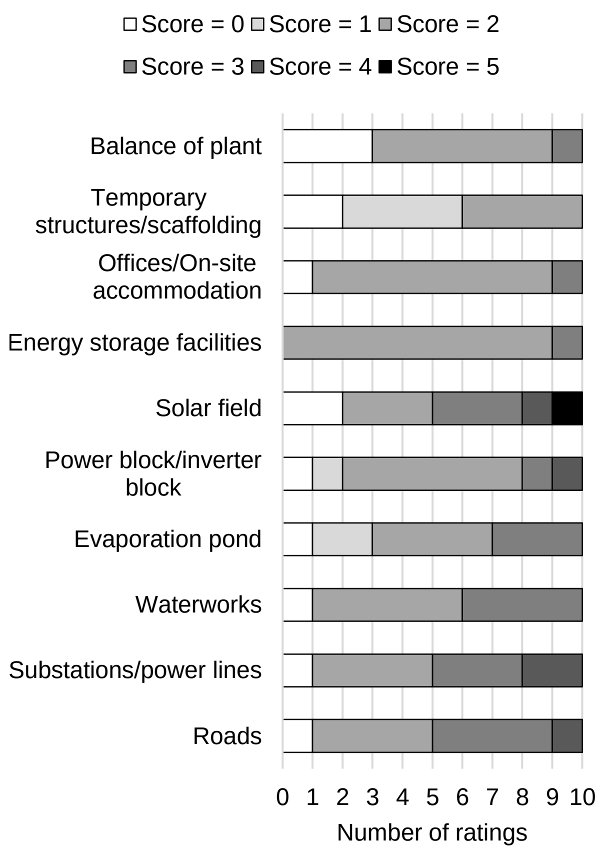


Figure G.8 Ratings for physical scale of impacts by different power plant components during CSP operation.

Table G.4 Number of ratings summarised per numerical score value for physical scale of impacts by power plant components during CSP construction and operation.

Power plant components	**Number of ratings for CSP construction physical scale**						**Number of ratings for CSP operation physical scale**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Roads	1	0	4	4	1	0	1	0	4	4	1	0
Substations/power lines	1	0	4	4	1	0	1	0	4	3	2	0
Waterworks	1	0	4	5	0	0	1	0	5	4	0	0
Evaporation pond	1	2	5	2	0	0	1	2	4	3	0	0
Power block/inverter block	1	2	5	2	0	0	1	1	6	1	1	0
Solar field	1	1	4	3	0	1	2	0	3	3	1	1
Energy storage facilities	0	0	8	2	0	0	0	0	9	1	0	0
Offices/On-site accommodation	1	0	8	1	0	0	1	0	8	1	0	0
Temporary structures/scaffolding	1	0	9	0	0	0	2	4	4	0	0	0
Balance of plant	3	0	5	2	0	0	3	0	6	1	0	0

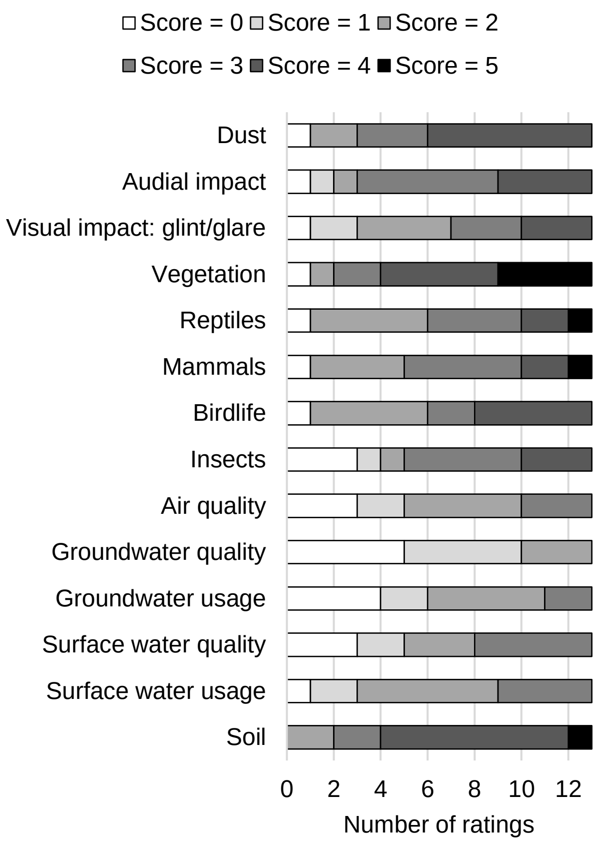


Figure G.9 Ratings for severity of impacts on different biophysical elements during PV construction.

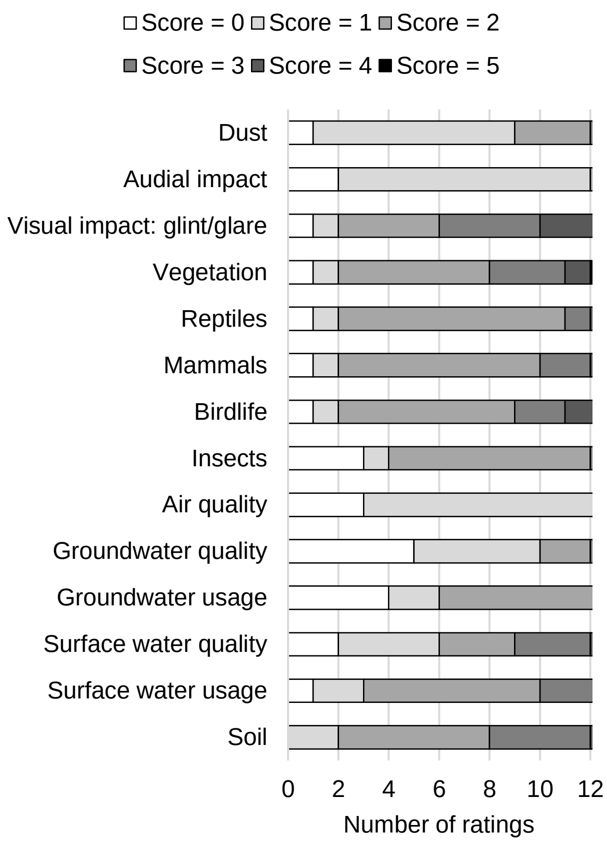


Figure G.10 Ratings for severity of impacts on different biophysical elements during PV operation.

Table G.5 Number of ratings summarised per numerical score value for impact severity on biophysical elements during PV construction and operation.

Biophysical elements	**Number of ratings for PV construction severity**						**Number of ratings for PV operation severity**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Soil	0	0	2	2	8	1	0	2	6	4	1	0
Surface water usage	1	2	6	4	0	0	1	2	7	3	0	0
Surface water quality	3	2	3	5	0	0	2	4	3	3	1	0
Groundwater usage	4	2	5	2	0	0	4	2	7	0	0	0
Groundwater quality	5	5	3	0	0	0	5	5	2	1	0	0
Air quality	3	2	5	3	0	0	3	10	0	0	0	0
Insects	3	1	1	5	3	0	3	1	8	1	0	0
Birdlife	1	0	5	2	5	0	1	1	7	2	2	0
Mammals	1	0	4	5	2	1	1	1	8	2	1	0
Reptiles	1	0	5	4	2	1	1	1	9	1	1	0
Vegetation	1	0	1	2	5	4	1	1	6	3	1	1
Visual impact: glint/glare	1	2	4	3	3	0	1	1	4	4	3	0
Audial impact	1	1	1	6	4	0	2	10	1	0	0	0
Dust	1	0	2	3	7	0	1	8	3	1	0	0

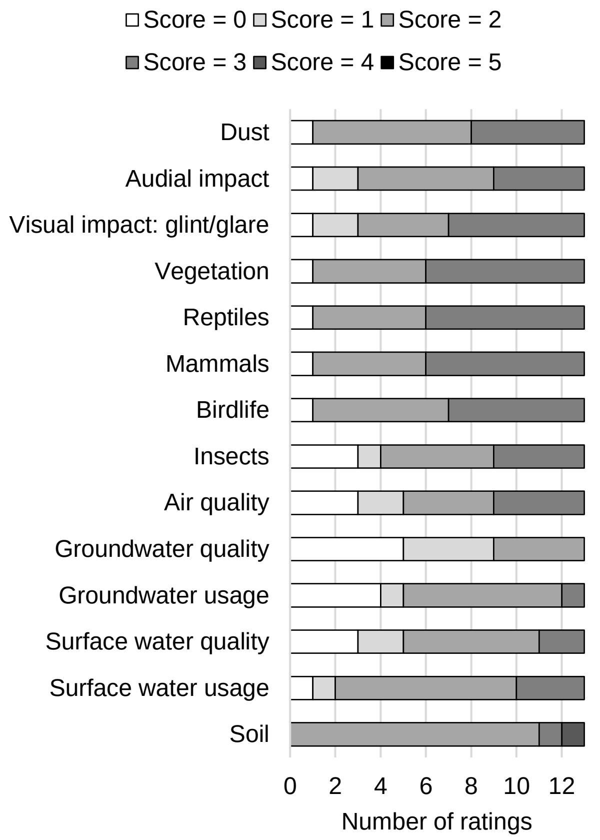


Figure G.11 Ratings for physical scale of impacts on different biophysical elements during PV construction

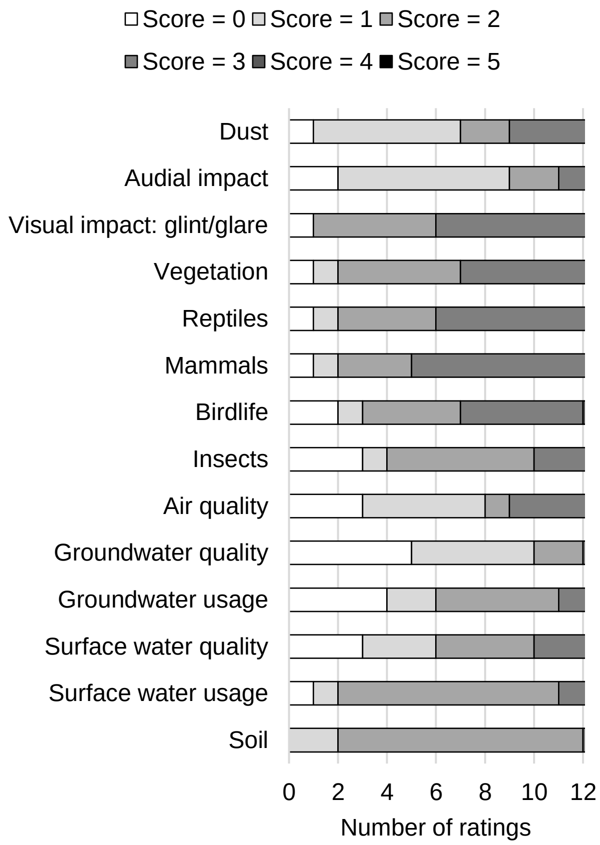


Figure G.12 Ratings for physical scale of impacts on different biophysical elements during PV operation

Table G.6 Number of ratings summarised per numerical score value for physical scale of impacts on biophysical elements during PV construction and operation.

Biophysical elements	**Number of ratings for PV construction physical scale**						**Number of ratings for PV operation physical scale**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Soil	0	0	11	1	1	0	0	2	10	1	0	0
Surface water usage	1	1	8	3	0	0	1	1	9	2	0	0
Surface water quality	3	2	6	2	0	0	3	3	4	3	0	0
Groundwater usage	4	1	7	1	0	0	4	2	5	2	0	0
Groundwater quality	5	4	4	0	0	0	5	5	2	1	0	0
Air quality	3	2	4	4	0	0	3	5	1	4	0	0
Insects	3	1	5	4	0	0	3	1	6	3	0	0
Birdlife	1	0	6	6	0	0	2	1	4	5	1	0
Mammals	1	0	5	7	0	0	1	1	3	8	0	0
Reptiles	1	0	5	7	0	0	1	1	4	7	0	0
Vegetation	1	0	5	7	0	0	1	1	5	6	0	0
Visual impact: glint/glare	1	2	4	6	0	0	1	0	5	7	0	0
Audial impact	1	2	6	4	0	0	2	7	2	2	0	0
Dust	1	0	7	5	0	0	1	6	2	4	0	0

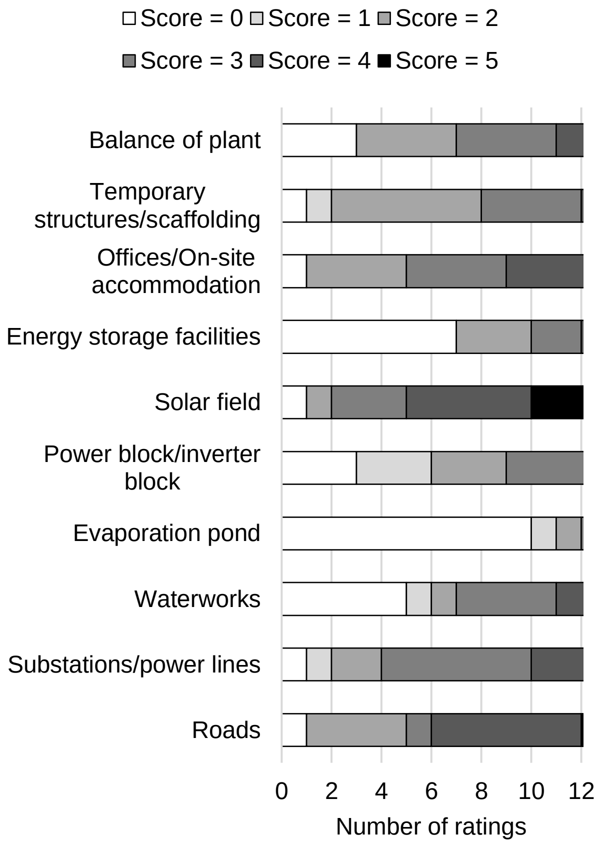


Figure G.13 Ratings for severity of impacts by different power plant components during PV construction.

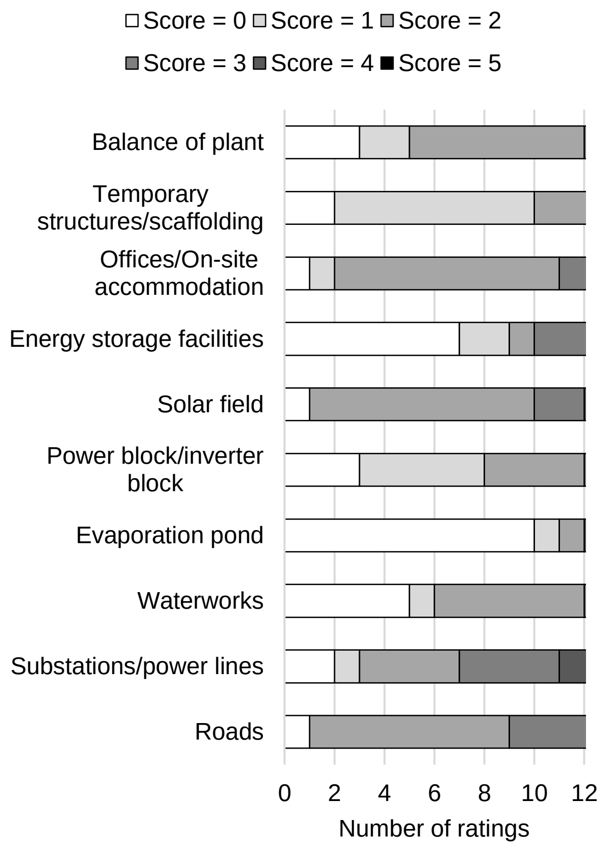


Figure G.14 Ratings for severity of impacts by different power plant components during PV operation.

Table G.7 Number of ratings summarised per numerical score value for severity of impacts by power plant components during PV construction and operation.

Power plant components	**Number of ratings for PV construction severity**						**Number of ratings for PV operation severity**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Roads	1	0	4	1	6	1	1	0	8	4	0	0
Substations/power lines	1	1	2	6	3	0	2	1	4	4	2	0
Waterworks	5	1	1	4	2	0	5	1	6	1	0	0
Evaporation pond	10	1	1	1	0	0	10	1	1	0	1	0
Power block/inverter block	3	3	3	4	0	0	3	5	4	1	0	0
Solar field	1	0	1	3	5	3	1	0	9	2	1	0
Energy storage facilities	7	0	3	2	1	0	7	2	1	3	0	0
Offices/On-site accommodation	1	0	4	4	4	0	1	1	9	2	0	0
Temporary structures/scaffolding	1	1	6	4	1	0	2	8	3	0	0	0
Balance of plant	3	0	4	4	2	0	3	2	7	1	0	0

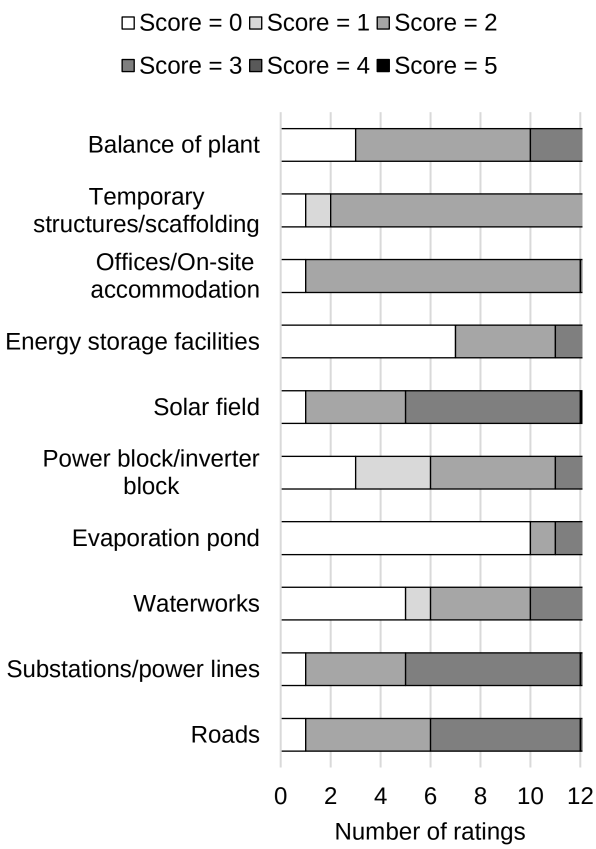


Figure G.15 Ratings for physical scale of impacts by different power plant components during PV construction.

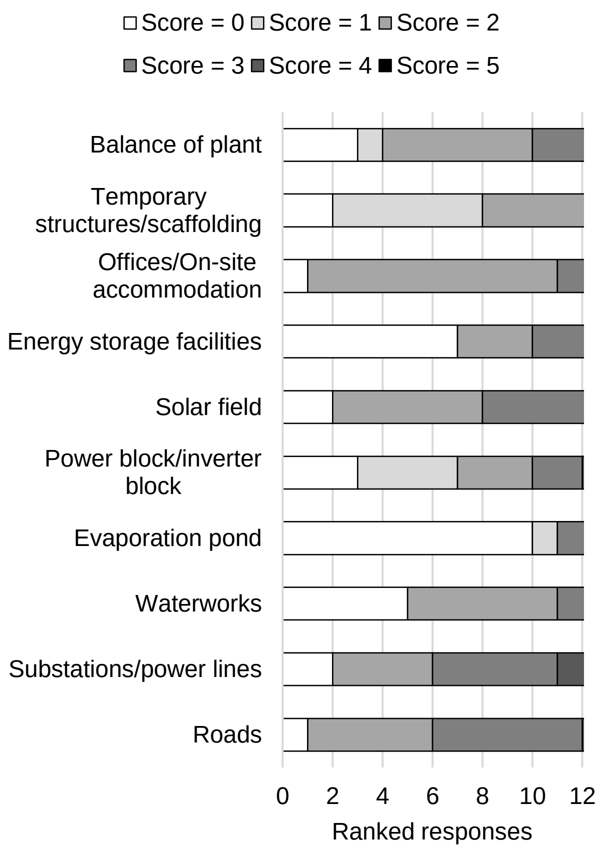


Figure G.16 Ratings for physical scale of impacts by different power plant components during PV operation.

Table G.8 Number of ratings summarised per numerical score value for physical scale of impacts by power plant components during PV construction and operation.

Power plant components	**Number of ratings for PV construction physical scale**						**Number of ratings for PV operation physical scale**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Roads	1	0	5	6	1	0	1	0	5	6	1	0
Substations/power lines	1	0	4	7	1	0	2	0	4	5	2	0
Waterworks	5	1	4	3	0	0	5	0	6	2	0	0
Evaporation pond	10	0	1	2	0	0	10	1	0	2	0	0
Power block/inverter block	3	3	5	2	0	0	3	4	3	2	1	0
Solar field	1	0	4	7	0	1	2	0	6	5	0	0
Energy storage facilities	7	0	4	2	0	0	7	0	3	3	0	0
Offices/On-site accommodation	1	0	11	1	0	0	1	0	10	2	0	0
Temporary structures/scaffolding	1	1	11	0	0	0	2	6	5	0	0	0
Balance of plant	3	0	7	3	0	0	3	1	6	3	0	0

H. P-VALUES FROM MANN-WHITNEY U TEST FOR NUMERICAL DATA OF SECTION 4 FOR SOLAR POWER

Table H.1 A summary of p-values for the comparison between construction and operation of various biophysical elements for both CSP and PV. P-values <0.05 are highlighted indicating a significant difference in the rating of the severity and physical scale of the associated impact for the two different stages of the development.

Biophysical element	CSP (n=10)		PV (n=13)	
	Severity	Physical scale	Severity	Physical scale
Soil	0.033	0.178	0.002	0.317
Surface water usage	0.984	0.694	0.803	0.761
Surface water quality	0.653	0.613	0.921	0.915
Groundwater usage	0.942	1.000	0.758	0.901
Groundwater quality	0.994	0.845	0.952	0.991
Air quality	0.156	0.699	0.033	0.740
Insects	0.721	0.943	0.080	0.881
Birdlife	0.699	0.930	0.010	0.415
Mammals	<0.001	0.891	0.001	0.428
Reptiles	<0.001	0.631	<0.001	0.238
Vegetation	0.004	0.011	0.004	0.115
Visual impact: glint/glare	0.064	0.527	0.533	0.115
Audial impact	0.078	0.343	<0.001	0.052
Dust	0.003	0.009	<0.001	0.074

Table H.2 A summary of p-values for the comparison between construction and operation of the impacts by various power plant components for both CSP and PV. P-values <0.05 are highlighted indicating a significant difference in the rating of the severity and physical scale of the associated impact for the two different stages of the development.

Power plant component	CSP (n=10)		PV (n=13)	
	Severity	Physical scale	Severity	Physical scale
Roads	0.128	0.860	0.039	0.910
Substations/power lines	0.149	0.972	0.323	0.877
Waterworks	0.009	0.885	0.330	1.000
Evaporation pond	0.964	0.562	1.000	1.000
Power block/inverter block	0.931	0.028	0.445	0.988
Solar field	0.444	0.795	0.002	0.266
Energy storage facilities	0.582	<0.001	0.832	0.980
Offices/On-site accommodation	0.398	0.635	<0.001	0.830
Temporary structures/scaffolding	0.019	0.057	0.001	0.039
Balance of plant	0.655	0.973	0.112	0.942

I. INTERVIEW RESPONSES OUTSIDE SCOPE OF STUDY FOR SOLAR POWER

Table I.1 A summary of the responses which were recorded on the potential impact of solar power which were not in scope of the thesis.

Socio-economic impacts mentioned	
Code	**Number of quotations**
Additional socio-economic challenges in local communities	2
Aesthetic impact of powerlines	1
Competition for water resources	0
Destruction of heritage resources	4
Economic impact	1
Electromagnetic interference/Radio-frequency interference	1
Good use of non-arable lands	1
High land-usage for power generated	1
Influx of derogatory social services	1
Influx of work seekers	1
Light pollution during construction and operation	1
Loss of agricultural land	5
Recycling and end-of-life challenges	4

Non-direct environmental impacts mentioned	
Code	**Number of quotations**
Disposal of waste products from molten salts	1
Embedded fossil energy	1
Good use of non-arable lands	1
Impact of mining of rear earth elements can be similar to coal mining across life cycle	1
Life cycle impacts and embedded energy	2
Loss of agricultural land	5
Mining of rear earth elements	2
Recycling and end-of-life challenges	4
Risk of toxic chemicals in PV panels	1

J. FIELD OBSERVATION NOTES

The following sub-sections summarise the findings and observations of the site visits under the appropriate headings, offering a practical perspective in addition to the data obtained through the interview process.

Animal-related findings

Animal encounters were recorded at all of the visited power plants and it is apparent that these encounters are recorded and duly taken care of if necessary, the 'culture' and context of these were unique to every contractor and/or operator in their specific location. There was confirmation from five of the power plants that no birds have been recorded to be confused by the PV panels or parabolic troughs and no collisions have been recorded in the solar fields. Birds resting on PV panels are a common occurrence. Sites 1, 5 and 6 were the only developments with evaporation ponds, and these act as a general attraction to species.

No roadkill had been recorded within the development footprints of any of the power plants, but there have been a number of incidents at the approaching public and private roads of sites 5 and 6. The general impression with regards to animal encounters at the visited power plants was that these facilities offer areas of attraction to certain species. Apart from the planned avian monitoring programme at site 5, there were no other formal faunal monitoring programmes in place at the visited sites.

***Site 1* -** Openings were made in the power plant fence to allow small animals to move into and out of the site footprint and as such many small animals were often seen on site. Rats are regarded as the largest 'problem animal' on site as they damage wires. An Aardvark (*Orycteropus afer)* was also found on site, but was removed and taken to a nearby game reserve due to risk of it damaging cables by burrowing. An owl (species not mentioned) was noticed nesting at the back of one of the panels during operation. As a recommendation from the ECO, the operation of that panel stopped until the species left the nest.

***Site 2* -** In addition to sheep grazing between and underneath the PV panels and infrastructure, animals which were mentioned as entering site by burrowing underneath the electrical fence include Hegehogs (*Atelerix frontalis*), Porcupines (*Hystrix africaneastralis*), Bat eared fox (*Otocyon megalotis*), Rabbits (no species mentioned), Rock monitor lizards (*Varanus albigularis*), Rinkhals (*Hemachatus haemachatus*), Cape cobra (*Naja nivea*) and Cape Ground Squirrels (*Xerus inauris*). The Cape Ground Squirrels and mice (no species mentioned) are a problem on site as they gnaw on wires, small birds such as Cape sparrows (*Passer melanurus*) also make nests in some of the structures. Bird nests (no species mentioned) are also commonly found in small openings of the transformer buildings. Termite mounds are regarded as a possible risk to inhibit movement between sites. No fatalities have been recorded on site.

***Site 3* -** Small animals that enter site by burrowing underneath fence include Steenbok (*Raphicerus campestris*), rabbits (no species mentioned), Springhare (*Pedetes capensis*), Rock monitor lizards and tortoises (no species mentioned); if the latter are found on site they are removed. Cape sparrows and other small birds make nests in transformer buildings. The only fatality recorded was a Cape cobra after causing a short circuit in a transformer building.

***Site 4* -** The site is fenced with an electrical fence with higher clearance to allow small animals to enter. The following have been seen on site: Suricate (*Suricata suricatta*), Cape cobras, Puff adders (*Bitis arietans*), Horned adder (*Bitis caudalis*), Karoo sand snake (*Psammophis notostictus*) and unspecified tortoise and rodent species. A disorientated Buzzard (species not mentioned) was found on site during construction; it was removed to recover and be released. At a later stage during construction a strange-behaving Striped polecat (*Ictonys striatus*) was found wondering around the temporary office buildings; the polecat also removed and thought to have suffered from rabies. No other casualties have occurred, and there have been no fatalities. During the site visit, a bird nest, similar to that of site 2, was observed on a transformer building. This was confirmed as the first nest of it's type at that particular site.

Site 5 - Lanner falcon (*Falco biarmicus*) and Pied crows (*Corvus albus*) are often seen around the solar field and power block and have been observed 'playing' around the areas of solar flux. Speckled pigeons (*Columba guinea*) are also commonly observed on site. Since the commencement of a commissioning and testing phase in September 2015, only three flux-related fatalities of unspecified swift, lark and pigeon species have been recorded. A number of Lesser flamingos (*Phoenicocnaias minor*) have been observed to approach the solar field as if they were intending on touching down, but as soon as the birds were close enough to better see the heliostats, they moved away again.

Several birds have been observed at the evaporation ponds, including a flock of 33 Lesser flamingos, a Martial eagle (*Polemaetus bellicosus*), and an African fish eagle (*Haliaeetus vocifer*). Black-winged stilts (*Himantopus himantopus*) are breeding in the evaporation ponds and have been observed to demonstrate territorial behaviours towards the birds of prey which were mentioned. Figure 3.10 shows an empty nest at the edge of an evaporation pond at site 5, presumably belonging to a pair of Black-winged stilts. An avian monitoring programme was about to start at this facility during the site visit.

Apart from occasionally observed domestic cats and dogs, no other animals have been recorded on site, and apart from the mentioned bird fatalities, no other casualties have occurred. A number of roadkill incidents have occurred due to speeding on one of the roads approaching the site. In one of these incidents, an Aardwolf (*Proteles cristata*) was killed with the driver unaware that the animal was trapped against the front of the car. No formal records of road incidents were presented.

Site 6 - Evaporation ponds are attracting birds, and Maccoa ducks are one of the species recorded to breed at the ponds. Three individual bird fatalities have been recorded: two Black-winged stilts, a species which has become territorial in the evaporation ponds, and one White-breasted cormorant (*Phalacrocorax lucidus*), which was not regularly recorded at the evaporation ponds. A specialist confirmed that these were of natural causes such as exhaustion.

Two mammal drownings were recorded at the evaporation ponds: one Bat eared fox and one Aardwolf (*Proteles cristata*). These occurred when the animals came to drink water, but could not exit the pond on the slippery lining. Roadkill due to speeding was also said to be a problem on a road approaching this site.

As the power plant is at the foot of a rocky outcrop, Puff adders, Black Spitting cobra (*Naja nigricollis woodi*) and Rock monitor lizards are seen on site.

Vegetation related findings

Due to the disturbed nature of the soil surface in development footprints, some weedy and pioneer plant species were observed at all of the sites. Vegetation regrowth was generally welcomed as a natural dust suppressing mechanism at all sites except site 6 as vegetation poses a more significant fire risk at this development.

Site 1 - All natural vegetation was removed prior to construction, but regrowth is encouraged during the operational phase as a natural dust suppressant.

Site 2 - Natural vegetation in solar field was left intact and still used for sheep grazing. The grass in between the panels and structures is cut occasionally using weed-eaters and conventional lawnmowers. During the site visit, the vegetation inside the development fence was observed to be denser than that outside of the fence.

Site 3 - Natural vegetation in solar field was mostly left intact. The grass in the solar field is cut twice a year. The host shared that Mexican poppies (*Argemone Mexicana*) have been found and removed from site.

Site 4 - Two 'green areas' were established and fenced off inside the development footprint where no construction took place and individual Kraal aloes (*Aloe claviflora*), which had been found in the solar field, were relocated prior to the start of construction.

Site 5 - After removal of all vegetation and topsoil, vegetation regrowth is now encouraged as a dust suppressant, and grass cutting will be implemented to minimise the risk of fire.

Prosopis juliflora is the most common invasive species on site, and no other aggressive invasive plant species have been recorded.

Site 6 - All vegetation and topsoil was removed from the entire development footprint and the soil was compacted afterwards. Plant individuals of possible significance included several *Hoodia gordinii* individuals, which were relocated from the development footprint to a similar land portion, and an unknown number of Stink Sheperd's Trees (*Boscia foetida*), which occurred in the development footprint but were destroyed due to the unlikely survival after relocation. Vegetation regrowth is not encouraged at this development as it poses a fire risk, and pioneering grass species are removed by hand approximately twice a year.

Soil- or erosion related findings

Soil impact was present at all visited developments, and the extent and management thereof are unique to each development. General findings related to soil- and/or erosion are summarised below.

The topsoil and vegetation in areas around the temporary and permanent site offices, the laydown areas, construction camps, roads, substations, transformer buildings (for PV sites) and the power blocks (for CSP) were cleared at all visited power plants. Trenches for cables and foundations or holes for pylons are common practice at all visited power plants; the depth of these vary from 300 mm, where the soil structure prohibits deeper digging, to 3 metres for the foundation of the central receiver tower at site 5. The average depth at which pylons are driven into the soil is 1.2 metres.

With exception of the construction camps, laydown areas and temporary office buildings, these areas will remain cleared and/or be covered with gravel, tarmac or concrete throughout the lifetime of the power plant. There was, however, variation with regards to the approach that was followed when constructing the solar fields at these developments. Vegetation and topsoil clearance prior to solar field construction was implemented at three of the visited developments (Site ID's: 1, 5 and 6). The dust impact at these sites was significant during construction, and at sites 5 and 6, a nearby community and farmer complained of being affected by the dust during these times. Based on hindsight, site managers advise future developers not to remove topsoil in the heliostat field. Topsoil that is removed from any area is stored at embankments where it is intended to be rehabilitated later. At site 5 there was significant mixture of topsoil with gravel material due to practices non-compliant to the EMPr, but these areas are showing positive signs of rehabilitation after two rainy seasons.

At the three other developments, vegetation and topsoil in the solar field was mostly kept intact, with the exception of smaller areas where pylons were driven into the soil and where machinery had to move during construction. The contractor at site 4 used the term 'light-on-ground' to describe this practice where vegetation disturbance is kept low as possible.

During the site visits it was noted that every development was experiencing problems with erosion during floods and needed to make impromptu changes to their storm water plans. These problems were primarily experienced because storm water plans did not follow natural drainage lines.

Water treatment and water usage related findings

Storm water management was problematic at all sites and needed to be addressed. The quantity of water used and the method of treatment was unique to every development. Observations related hereto are summarised below.

Site 1- Operational water is sourced from a nearby borehole and distilled at an on-site facility. Excess water from the distillation process is contained in a sealed evaporation pond. Distilled water is used to wash panels every six weeks; the water quantity for this activity was not given.

Site 2 - Water for all the development's needs is sourced from a nearby borehole, and a purification system has not yet been installed. Module-washing is not really seen as needed by operators, but is done every six months as a rule using biodegradable soap. The water quantity for this activity was not given.

Site 3 - The modules at this development are washed twice a year with borehole water only; no water use quantities were given.

Site 4 - As the development is still in the construction phase, no module washing has taken place. Operational water for the development will be purified and sourced from a municipality nearby, and no chemicals will be used for module washing.

Site 5 - The development has an annual water-use permit to extract 300 000 m^3 from the Orange River. This quantity covers all operation water uses on site, including the water needs of the steam cycle and heliostat-washing. The water that goes into the steam cycle is prepared by undergoing filtration, tri-osmosis and electronic deionization after which a number of chemicals from a chemical treatment facility is added. A zero discharge policy is in place, and no waste water is allowed to flow back into the environment, but goes to double lined evaporation ponds. The evaporation ponds all have a capacity of about 26 000 m^3. The ponds were reaching noticeably high levels at the time of the site visit due to technical challenges experienced during the commissioning phase.

Site 6 - The water at this development is also sourced from the Orange River, and once fully constructed will undergo the same treatment and preparation as that of site 5, but has an annual water-use permit to extract 400 000 m^3. This development will also operate with a zero-discharge policy where waste water goes to the triple-lined evaporation ponds.

Findings related to hazardous chemicals and risk of spillage

The 'risk of aerial or leachable toxic chemicals' was recorded as one of the most quoted impacts within a number of the most prominent biophysical impact categories and observations. Related impacts were also made during the site visits and are summarised below.

***Site 1* -** Some oil spillage occurs at the oil-cooled transformers; these are captured in water containers and separated in separation tank contained within bund walls.

***Site 2* -** No chemical spills were observed or mentioned.

***Site 3* -** Oil spills from oil-cooled transformers get removed to a hazardous waste site. There is some concern for leaching occurring from broken thin film modules stored on site. These are kept in a construction area and transported to a recycling plant as soon as the batch is large enough.

***Site 4* -** Only usual spills related to construction activities observed. This site also has oil-cooled transformers.

***Site 5* -** Hydraulic fluid spills regularly occur underneath heliostats. These are picked up and the soil treated on site using a biological treatment agent. Further ad hoc spills of chemicals occur when 'flushing' of power block components take place. The water treatment facility and chemicals are contained within bund walls.

***Site 6* -** Due to the lessons learnt from this development's neighbour, Kaxu Solar One, the facilities are built with much more care and within a safety margin to contain any accidental spills. Accidents related to chemicals and hazardous substances occurring at Kaxu include leakage and spillage of HTF, which gets treated with a biological agent, and a large spillage of molten salt (non-hazardous), which solidifies when reaching temperatures below 230 °C, thus eliminating the risk of leaching.

Findings specifically related to construction or operation

In addition to the findings related to specific topic areas given in the previous sub-sections, findings specifically related to construction or operation are given below.

Sites 3, 4 and 6 where still in construction phase during the site visits, and the expected construction related activities were observe, *i.e.,* dust, littering, noise and concrete spills – of which the impact of dust (especially at site 6) and storm water management was seemingly the most significant.

The observed impacts that stood out during the operational phases of sites 1, 2 and 5 were the various interactions with animals being attracted to the development infrastructure and the challenges these bring to operators.

Additional findings from site visits

Similar to findings from the interviews that fall out of scope, some discoveries were made during site visits which fall out of the direct environmental scope, but were interesting to note. Site 3 had a unique heritage feature where Later Stone Age and Pleistocene material was found in abundance on a hill, which was excluded from the development footprint.

Furthermore, it was noted during the site visits that human-human interactions on a corporate level plays a key role in how environmental impacts are managed. The corporate governance of all companies at the different developments was markedly different, and the approach to how environmental encounters and dynamics are managed seemed to be a direct product thereof.

K. ADDITIONAL SPATIAL RESULTS FOR SOLAR POWER DEVELOPMENT

Table K.1 The number and percentage of all approved solar power EIA applications and projects selected as preferred bidders throughout the first three rounds of the REIPPPP within certain distances of IBAs.

Proximity to Important Bird Areas	Number and (percentage) of approved solar EIA applications within given distance from an IBA			Number and (percentage) of approved solar EIA applications of preferred bidders within given distance from an IBA		
	CSP	**PV**	**Total**	**CSP**	**PV**	**Total**
0-1 km	1 (0.4%)	9 (3.6%)	**10 (4%)**	0	1 (4%)	**1 (4%)**
1-5 km	2 (0.8%)	6 (2.4%)	**8 (3.2%)**	0	1 (4%)	**1 (4%)**
5-10 km	0	7 (2.8%)	**7 (2.8%)**	0	1 (4%)	**1 (4%)**
>10 km	14 (5.6%)	210 (84.3%)	**224 (89.9%)**	3 (11%)	21 (77%)	**24 (88%)**

Table K.2 An indication of possible future biome transformation by solar power development based on the simple assumption that the relative location of solar power development remains the same and all allocated capacity for CSP and PV in the IRP Update gets built.

Biome	Total area transformed based on future scenario (km^2)	Percentage of total biome under solar power development in future scenario
Nama-Karoo Biome	3900.2	1.57%
Savanna Biome	1267.5	0.31%
Grassland Biome	92.8	0.03%
Fynbos Biome	168.9	0.19%
Succulent Karoo Biome	28.4	0.04%
Azonal Vegetation	59.1	0.18%
Albany Thicket Biome	-	-
Desert Biome	29.9	0.42%
Indian Ocean Coastal Belt	-	-

L. MAP OF KAROO BASIN

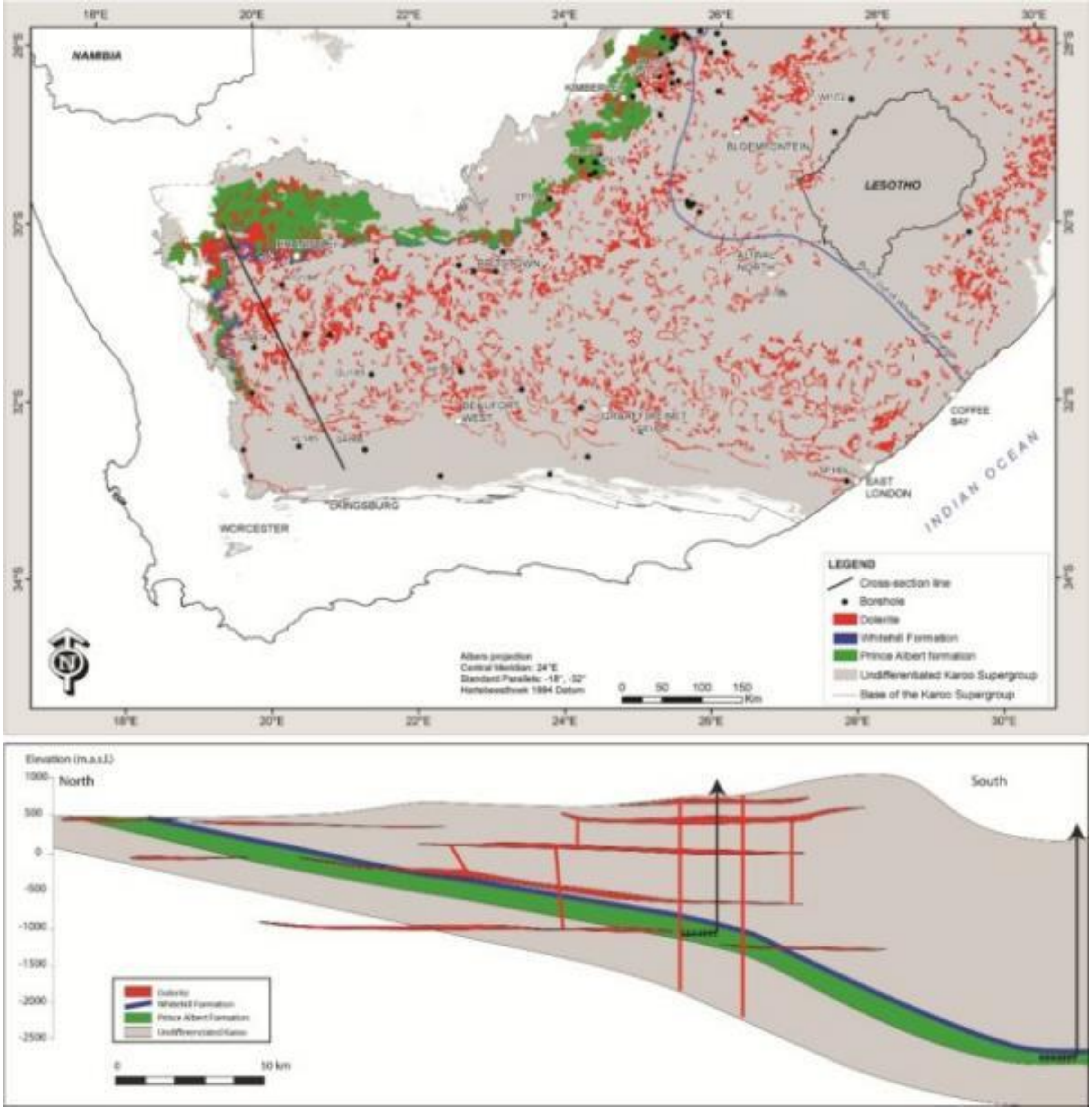


Figure L.1 A map showing the distribution of the Karoo Basin and the distribution of dolerite intrusions (top); and cross-sectional diagram showing the relative positions of the Whitehill and Prince Albert formations. Source: Council for Geosciences (2015).

M. PREVIOUS STUDIES OF SHALE GAS DEVELOPMENT IN SOUTH AFRICA

Table M.1 A summary of nationally coordinated studies throughout the past few years regarding shale gas development. Where a single year is indicated it represents the year in which a report(s) were published after the respective study.

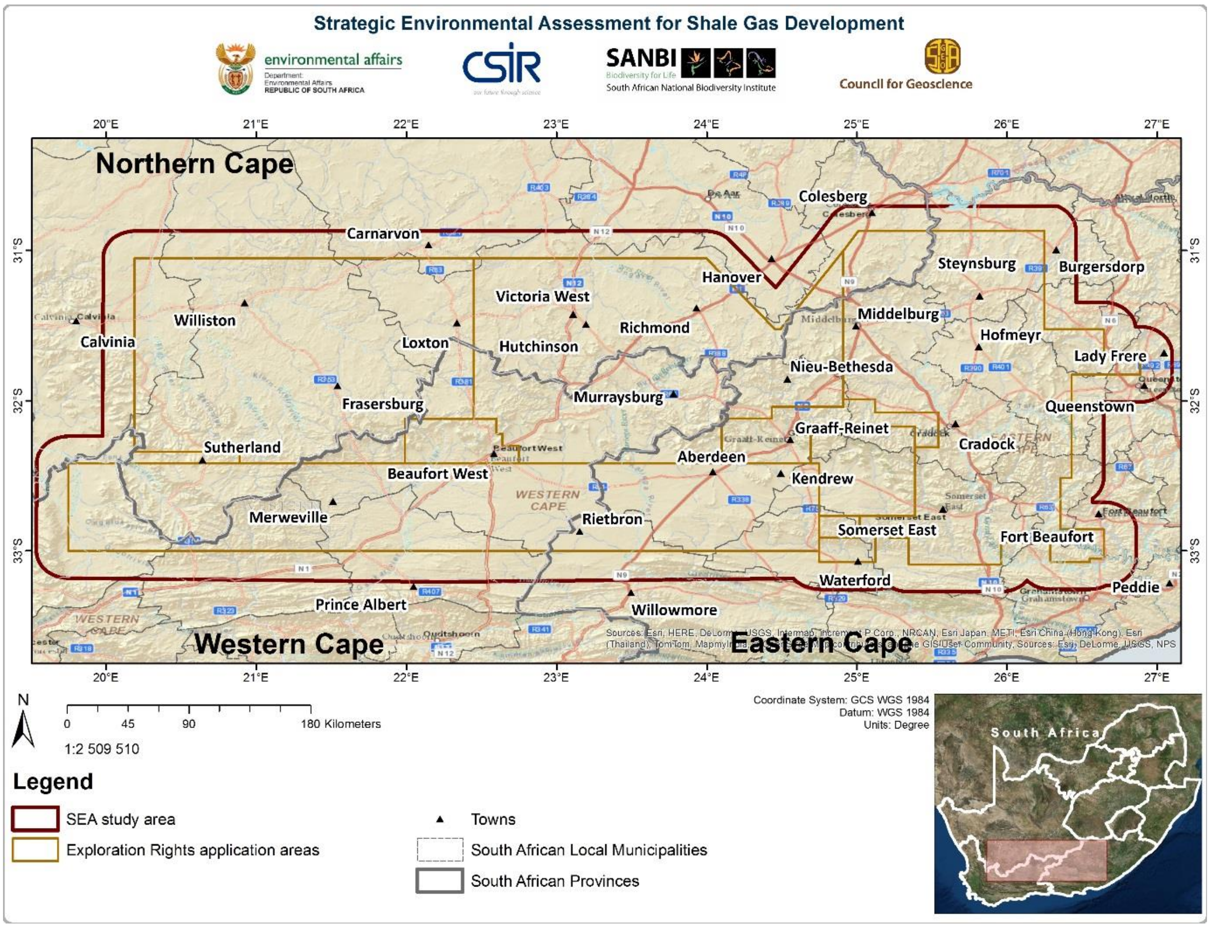
Year	Study title	Responsible entity(s) and Reference
2012	**State of the Art: Fracking for Shale Gas Exploration in South Africa and the Impact on Water Resources. WRC Report No. KV 294/11**	Researchers from University of the Free State and Council for Geoscience on the request of the Water Research Commission. (Steyl et al. 2012)
*2*012	**Investigation of Hydraulic Fracturing in the Karoo Basin of South Africa**	A Working Group, chaired by CEO of PASA the time and contributed to by representatives of DEA, Department of Science and Technology, DMR, DWA, PASA, Council for Geoscience, Square Kilometre Array, WRC and Eskom. (Mills et al. 2012)
2014	**Development of an Interactive Vulnerability Map and Monitoring Framework to Assess the Potential Environmental Impact of Unconventional Oil and Gas Extraction by Means of Hydraulic Fracturing. WRC Report No. 2149/1/14**	Researchers from the Centre for Environmental Management at the University of the Free State on the request of the Water Research Commission. (Esterhuyse et al. 2014)
2014 start 2016 first results	**Karoo Research Initiative (KARIN)**	A team of geoscientists from SA's leading universities, coordinated under the Department of Science and Technology's Centre of Excellence for Integrated Mineral and Energy Resource Analysis. (CIMERA 2014)
2014-2017	**Shale gas research project at Nelson Mandela Metropolitan University*** **Not nationally coordinated, but government-funded. Focus limited to Eastern Cape.*	Nelson Mandela Metropolitan University and the Eastern Cape Department of Economic Development, Environmental Affairs and Tourism. (NMMU 2014)
2015-2017	**Strategic Environmental Assessment for Shale Gas Development**	CSIR, SANBI and Council for Geosciences as appointed by the DEA. (Scholes et al. 2016)

N. SCOPE OF STRATEGIC ENVIRONMENTAL ASSESSMENT FOR SHALE GAS DEVELOPMENT (SEASGD)

The governance scope and timeline of the SEASGD was carefully planned and determined, and it was stretched over three overlapping phases (preparation, assessment, decision-support outputs) from February 2015 to March 2017.

The following points summarise the scope of work and procedure followed in the SEASGD:

- The SEA study area is the same area as the areas where exploration right applications have been received, but includes additional 20km buffer around these areas. The area is shown below.



- Both exploration and production phases and related activities of shale gas development are assessed in the SEA
- The strategic issues which are assessed in the SEA are
    1. Effects on National Energy Planning and Energy Security
    2. Air Quality and Greenhouse Gas Emissions
    3. Earthquakes
    4. Surface water and Groundwater resources
    5. Waste Planning and Management
    6. Biodiversity and Ecology
    7. Agriculture
    8. Tourism

9. Economy
10. Social Fabric of 34 Municipalities
11. Human Health
12. Sense of Place
13. Visual, Aesthetic and Scenic Resources
14. Heritage
15. Noise Generated by Shale Gas-related Activities
16. Electromagnetic Interference
17. Infrastructure and Spatial Planning

- These strategic issues are addressed by multi-author teams; each strategic issue has a team of three to six authors, ranging from integrating authors to contributing- and corresponding authors.
- Chapters written by multi-author teams are externally reviewed by expert reviewers, and second draft chapters are then made available for stakeholder review.
- Strategic issues are assessed using a risk assessment approach that assigns risk for all significant stressors on receiving entities in a qualitative manner and guided be a predefined set of criteria.
- More information about the SEASGD is available at: http://seasgd.csir.co.za/

O. SUMMARY OF FINDINGS OF SELECTED CHAPTERS IN THE SEASGD

Of the 17 topics which were assessed in the SEA and reported on in Chapters, the impacts of the following topics are relevant to the direct environmental impacts of shale gas and are summarised here: Ch. 3 Air Quality and Greenhouse Gas Emissions (Winkler et al. 2016), Ch. 4 Earthquakes (Durrheim et al. 2016), Ch. 5 Surface water and Groundwater resources (Hobbs et al. 2016), Ch. 6 Waste Planning and Management (Oelofse et al. 2016), and Ch. 7 Biodiversity and Ecology (Holness et al. 2016). A summary of the environmental impacts within these topics are summarised below.

Chapter 3: Air Quality and Greenhouse Gas Emissions

- All stages of shale gas development contribute to air pollutant emissions, which potentially results in a large geographical area affected by several relatively small point sources (e.g., activities on well pads), mobile sources (e.g., vehicles) and fugitive sources (e.g., leaking infrastructure components).
- A high risk of on-site air pollutants such as exhaust gas from diesel vehicles, NO_2, Particular Matter, volatile organic carbons, silica and H_2S as a highly toxic gas. In the 'Big Gas' scenario the total of these emissions could add up to approximately 18 tons per day.
- Local air pollution is at risk of increasing and further exceeding National Ambient Air Quality Standards, especially from the increase in Particulate Matter concentrations. The NO_x levels from shale gas production will dominate local emissions in the Central Karoo even at the level of shale gas exploration, but it remains below the National Ambient Air Quality Standards in the 'Big Gas' scenario.
- Baseline air quality information and monitoring is absent in the Karoo, which presents a critical limit to known air quality conditions prior to shale gas development.
- Depending on whether gas will replace coal or be used in addition to coal, shale gas can reduce or increase national GHG emissions. The reduction potential over the shale gas development life cycle when replacing coal is minimal with respect to the current GHG emissions.
- The use of shale gas for electricity generation instead of renewable energy or nuclear was found to have a low risk of increased GHG emissions.
- Replacing imported fuels and liquid fuels refined in South Africa with shale gas in gas-to-liquid facilities was found to have moderate risk of increased GHG emissions.
- Due to the high greenhouse warming potential of methane, there is a high risk of fugitive methane emissions to reverse GHG benefits.

Chapter 4: Earthquakes

- Hydraulic fracturing is associated with an increased probability of small tremors near well bores. Damaging earthquakes (magnitude ≥ 5) can occur where hydraulic fracturing co-occurs with a fault line, but are internationally almost always caused by waste water disposal into geological formations.
- Southern Africa is regarded as a seismically quiet region, but the Cape Fold Belt is seismically active, and the largest recorded seismic event in the study area occurred in the Ceres area in 1969 with a magnitude of 6.3.
- In case of the 'Big Gas' scenario, there is a likelihood that noticeable earthquakes surrounding production wells will increase, but this depends on the location of wells, the proximity to faults and the rate of hydraulic fracturing.

- The risk of damage-causing earthquakes in the study area is found to be low under all four scenarios.
- Before hydraulic fracturing commences, a network for seismographs will be needed to monitor seismicity throughout operation activities until well closure.

Chapter 5: Surface water and Groundwater resources

- Both surface water and groundwater resources are already severely constrained in the study area, and the capacity to use local sources for shale gas development is very limited. Cumulative impacts on water resources from other activities in the area increases concern for water quality and quantity.
- The impact on water resources are expected to be minimal during exploration, and these requirements should be able to be met by existing groundwater resources. The water requirements for the hydraulic fracturing of appraisal wells and, even more so, production wells will need to be met from water sourced outside the study area. The risk associated with spills and contaminations increases by orders of magnitude during production activities.
- Several of the major towns in the study area are currently experiencing a water deficit or have experienced a water shortage in the past 10 years.
- Non-potable groundwater sources could potentially be developed for hydraulic fracturing to a limited extent, but might potentially have impacts related with transport, storage and water wellfield development.
- Depending on the component water being reused, the expected water usage is approximately 70 140 m^3 - 103 770 m^3 per drill rig during the exploration stage and from 2 796 750 m^3 – 4 104 375 m^3 per drill rig during the ‘Big Gas’ Scenario.
- Accidental surface spills of toxic material on well pads and during transports poses a high risk to water resource contamination. Spills might have a short-term local impact, but downstream impacts can occur, e.g., if a spill comes in contact with a river during a flood event.
- The legacy of water impacts after shale gas development is a concern from a traceability, detection and timing perspective as to the source of funding for remediation and the number of closed wells in the environment increases this risk.
- With mitigation the risks of direct impacts to groundwater and surface water resources were found to be low, with exception to the reduced water availability for other uses in the study area and the contamination of surface water resources if contact with contaminated groundwater resources occurs.
- Baseline water source data for the study area is needed before shale gas development commences, which must include quality and quantity data. Continued monitoring during and after shale gas development is also essential.
- The Reserve needs for basic human and ecological requirements of the study area must be determined before any water use licenses can be issued for shale gas development.

Chapter 6: Waste Planning and Management

- Substantial volumes of new types of waste are expected to be generated in the study area. These waste types include fluid wastes, solid mining wastes, industrial wastes and an increase in conventional sewage, domestic water and construction waste.

- The severity of a waste-related incident will be determined by three characteristics: volume, degree of containment and the material characteristics (waste or wastewater).
- Waste-related risks are considered low if existing waste management legislation is rigorously enforced. The Petroleum Exploration and Development regulations of 2015 are mandatory and should not be relaxed as comprehensive site design and waste disposal regulations were included here.
- Deep well injection of wastewater and the dumping of waste- or flow back water in surface water bodies are prohibited in South Africa. Treated wastewater may be discharged into surface water resources only if the water meets the quality standard of the water use license.
- The study area currently offers no licensed hazardous waste treatment facilities and current municipal waste treatment technologies and capacities are inadequate for treating shale gas development waste. Due to the Naturally Occurring Radioactive Materials (NORMS), salinity and a range of toxic chemical additives, leach management and treatment is of particular concern.
- Without mitigation, all risks related to waste on-site and at municipal treatment facilities were found to be high for the 'Big Gas' scenario. With mitigation, the risks were found to be low at all exposure sites.

Chapter 7: Biodiversity and Ecology

- Areas with relatively high biodiversity, very unique and sensitive ecosystems and species are included in the study area and impacts in these areas could put the ecological integrity of the study area at risk.
- The overall level of terrestrial biodiversity endemism is relatively low throughout the study area, and although there are a number of known threatened aquatic faunal species associated with permanent water bodies, not much is known about the fauna of the seasonal ecosystems in the study area.
- Areas with high to very high ecological importance and sensitivity represent about 55% of the study area and only 5% is formally protected. Where impacts in these areas can't be avoided, alternative sites must be secured to ensure no net loss of biodiversity.
- Protection of the high and very high ecologically important and sensitive to free-up areas of low to medium ecological importance is seen as the primary mitigation for biodiversity impact associated with shale gas development. Environmental compliance remains relevant in areas with low to medium ecological importance.
- Ecological processes in the arid ecosystems of the Karoo operate over large areas and are sensitive to disturbance. Impact mitigation should be focused at landscape scale rather than at development footprint-level. Noise-, pollution-, erosion- and disturbance impacts extend well past the footprint for species, ecosystems and ecological processes. The loss of connectivity and habitat fragmentation of roads, pipelines and powerlines is thus a primary concern for undermining the biodiversity's integrity of the study area.
- Linking to the previous point, cumulative impacts resulting from repeated impacts across the landscape as well as widespread impacts have been identified as a major concern. It was calculated that under the 'Big Gas' scenario over four 30 x 30 km development blocks, the transformed area would be 6400 ha for well pads and 800 ha to access roads. Effectively this level of development results in 54% of the area in this block within 500 m of an access road or well pad and 86% of the area within 1 km of an access road or well pad. This also showed that the number and area occupied by roads weighs in more with higher well pad development intensity.

P. RECORD OF CODES IN IMPACT CATEGORIES OF THEME 1 FOR SHALE GAS

Table P.1 A summary of the codes and number of quotations per code for impact categories coded for Chapter 5 on the potential impact of shale gas.

Impact category and code	Number of quotations
Atmospheric/audial impacts	
Atmospheric pollution/methane emissions	8
Audial impact	3
Risk of aerial or leachable toxic chemicals	3
Visual and dust impact	5
Light impact of flaring gas at well pads	2
No tracking or recording of emissions	1
Biodiversity and ecology impacts	
Disposal of waste products from molten salts	1
Ecotoxilogical impact in food chain	1
Continuous impact due to traffic	3
Impact on local ecology & biodiversity	3
Risk of aerial or leachable toxic chemicals	3
Risk of large areas of land being contaminated	1
Risk of radioactive material exposure to environment	1
Risk of well failure after closure	1
Impacts on fauna	
Evaporation ponds as attraction to species	1
Hindrance to animal movement	1
Human and animal health impacts	1
Impacts on flora	
Vegetation clearance	1
Impacts on water	
Disposal of waste products from hydraulic fracturing	1
Groundwater contamination	9
Impact on surface water quality	7
Impact on total water resource availability	7
Risk of aerial or leachable toxic chemicals	3
Risk of well failure after closure	1
SA/Karoo too water scarce	3
Landscape impact	
Continuous impact due to traffic	3
Cumulative impacts of well pads across landscape not understood	1
Disposal of waste products from hydraulic fracturing	1
Habitat fragmentation	5
Habitat transformation/loss	5
Land impact by associated infrastructure	5

Risk of large areas of land being contaminated	1
Risk of radioactive material exposure to environment	1
Soil/geological impacts	
Disposal of waste products from hydraulic fracturing	1
Risk of large areas of land being contaminated	1
Risk of radioactive material exposure to environment	1
Seismic impact/could be linked to increase earthquakes	2
Risk of aerial or leachable toxic chemicals	3
Uncertainty related to deep subsurface drilling	1

Q. INTERVIEWS RESPONSES RELATED TO THE UNCERTAINTY OF SHALE GAS DEVELOPMENT

Table Q.1 A summary of the codes related to the uncertainty of shale gas development in the Karoo Basin.

Code	Number of quotations
Cause and effect hard to link, creating loopholes	2
Combined impact of SGD could be a disaster	1
Detailed shale gas study for every step of development needed	1
Dispute of contamination of gas is not well understood	1
High possibility that there might not even be shale gas in SA	2
Secrecy of exploration companies is not good	2
SGD seems very high risk given all uncertainty	1
Too many unknowns to understand impacts	4
Uncertainty if exploration will be on hold until all baseline studies are done	1
Uncertainty regarding accountability and liability	1

R. P-VALUES FROM MANN-WHITNEY U TEST FOR NUMERICAL DATA OF SECTION 4 FOR SHALE GAS

Table R.1 A summary of p-values for the comparison between exploration and construction, construction and production and exploration and production of severity and physical scale of impacts on various biophysical elements. P-values <0.05 are highlighted indicating a significant difference in the rating of the severity and physical scale of the associated impact between the two respective stages of the development.

	Severity			**Physical scale**		
Biophysical element	**Expl/Cons**	**Cons/Prod**	**Expl/Prod**	**Expl/Cons**	**Cons/Prod**	**Expl/Prod**
Soil	0.481	0.047	0.875	0.145	0.101	0.390
Surface water usage	0.170	0.795	0.474	0.252	0.975	0.388
Surface water quality	0.124	0.923	0.187	0.705	0.682	0.488
Groundwater usage	0.001	0.072	0.001	0.153	<0.001	0.023
Groundwater quality	0.070	0.053	0.004	0.166	<0.001	0.002
Air quality	0.285	0.591	0.128	0.426	0.674	0.210
Insects	0.421	0.731	0.643	0.779	0.550	0.408
Birdlife	0.359	0.796	0.331	0.833	0.716	0.370
Mammals	0.453	0.836	0.148	0.546	0.960	0.255
Reptiles	0.285	0.679	0.417	0.546	0.926	0.693
Vegetation	0.126	0.480	0.625	0.624	0.988	0.417
Visual impact: glint/glare	0.719	0.959	0.726	0.947	0.803	0.707
Audial impact	0.586	0.922	0.610	0.977	0.999	0.777
Dust	0.251	0.587	0.719	0.774	0.889	0.626

Table R.2 A summary of p-values for the comparison between exploration and construction, construction and production and exploration and production of severity and physical scale of impacts by various infrastructure components. P-values <0.05 are highlighted indicating a significant difference in the rating of the severity and physical scale of the associated impact between the two respective stages of the development.

Infrastructure component	**Severity**			**Physical scale**		
	Expl/Cons	**Cons/Prod**	**Expl/Prod**	**Expl/Cons**	**Cons/Prod**	**Expl/Prod**
Roads	0.010	0.943	0.012	0.324	0.884	0.406
Gas infrastructure	0.079	0.936	0.290	0.067	0.914	0.088
Well pads	0.003	0.749	0.044	0.104	0.671	0.024
Subsurface drilling	< 0.001	0.670	0.012	0.414	0.782	0.152
Well-casing construction	0.354	0.774	0.553	0.681	0.850	0.793
Hydraulic fracturing	0.194	0.742	0.127	0.194	0.428	0.096
Evaporation ponds	0.113	0.464	0.034	0.174	0.002	0.023
Water recycling	0.164	0.487	0.416	0.280	0.888	0.453
Waste water disposal	0.287	0.660	0.343	0.094	0.819	0.201
‘Frac’-fluid storage	0.037	0.406	0.012	0.064	0.889	0.038
Offices/On-site accommodation	0.117	0.488	0.036	0.178	0.718	0.018

S. SUMMARY OF NUMERICAL RATINGS FROM INTERVIEWS FOR SHALE GAS

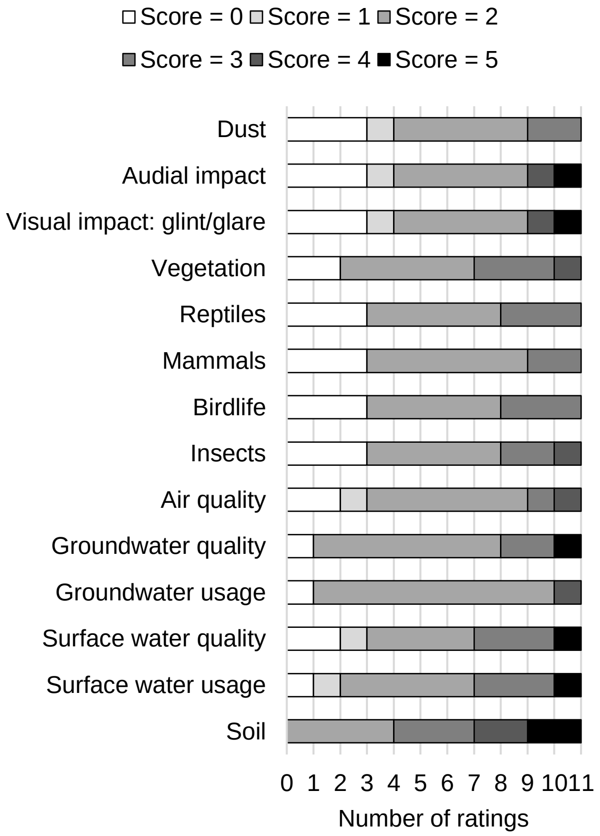


Figure S.1 Ratings for severity of impacts on different biophysical elements during shale gas exploration.

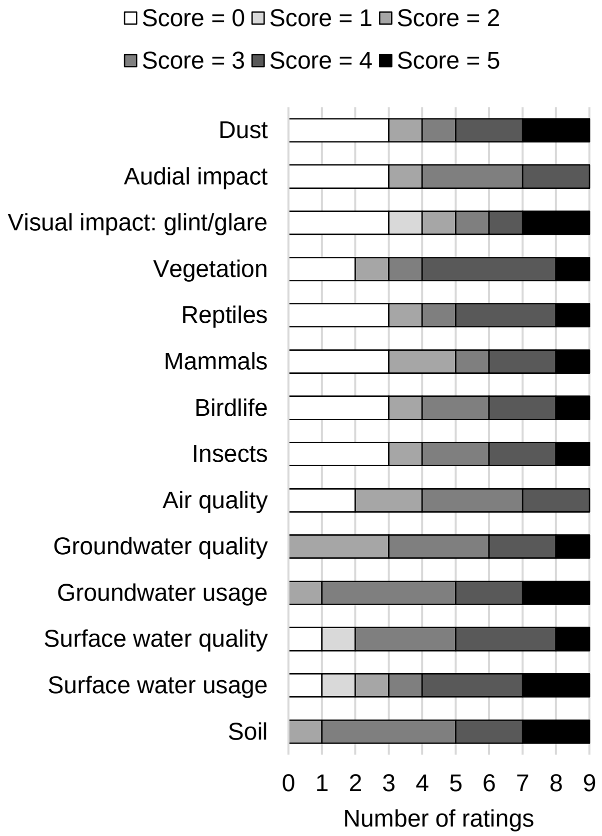


Figure S.2 Ratings for severity of impacts on different biophysical elements during shale gas construction.

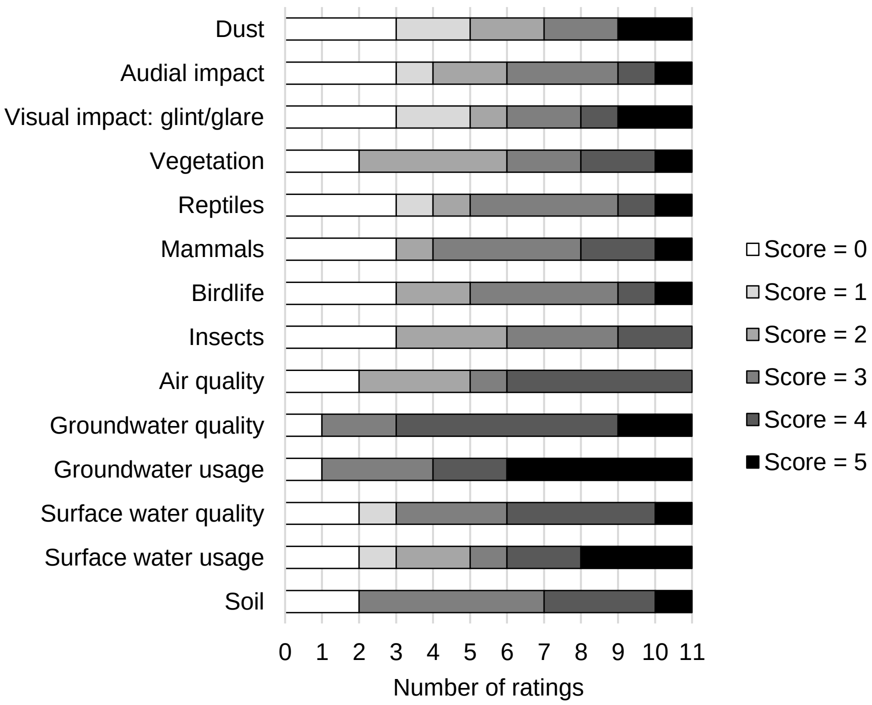


Figure S.3 Ratings for severity of impacts on different biophysical elements during shale gas production.

Table S.1 Number of ratings summarised per numerical score value for impact severity on biophysical elements during shale gas exploration, construction and production.

Biophysical elements	Exploration						Construction						Production					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Soil	0	0	4	3	2	2	0	0	1	4	2	2	2	0	0	5	3	1
Surface water usage	1	1	5	3	0	1	1	1	1	1	3	2	2	1	2	1	2	3
Surface water quality	2	1	4	3	0	1	1	1	0	3	3	1	2	1	0	3	4	1
Groundwater usage	1	0	9	0	1	0	0	0	1	4	2	2	1	0	0	3	2	5
Groundwater quality	1	0	7	2	0	1	0	0	3	3	2	1	1	0	0	2	6	2
Air quality	2	1	6	1	1	0	2	0	2	3	2	0	2	0	3	1	5	0
Insects	3	0	5	2	1	0	3	0	1	2	2	1	3	0	3	3	2	0
Birdlife	3	0	5	3	0	0	3	0	1	2	2	1	3	0	2	4	1	1
Mammals	3	0	6	2	0	0	3	0	2	1	2	1	3	0	1	4	2	1
Reptiles	3	0	5	3	0	0	3	0	1	1	3	1	3	1	1	4	1	1
Vegetation	2	0	5	3	1	0	2	0	1	1	4	1	2	0	4	2	2	1
Visual impact: glint/glare	3	1	5	0	1	1	3	1	1	1	1	2	3	2	1	2	1	2
Audial impact	3	1	5	0	1	1	3	0	1	3	2	0	3	1	2	3	1	1
Dust	3	1	5	2	0	0	3	0	1	1	2	2	3	2	2	2	0	2

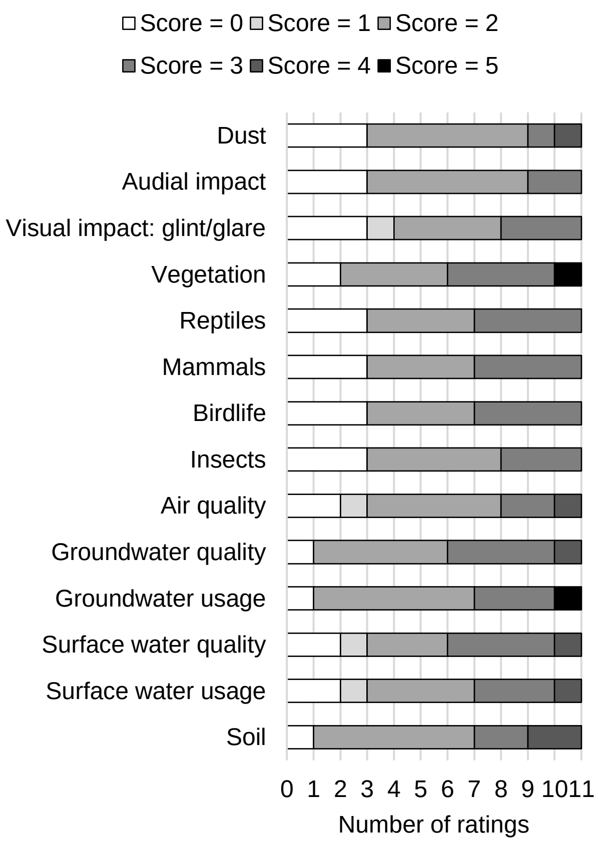


Figure S.4 Ratings for physical scale of impacts on different biophysical elements during shale gas exploration.

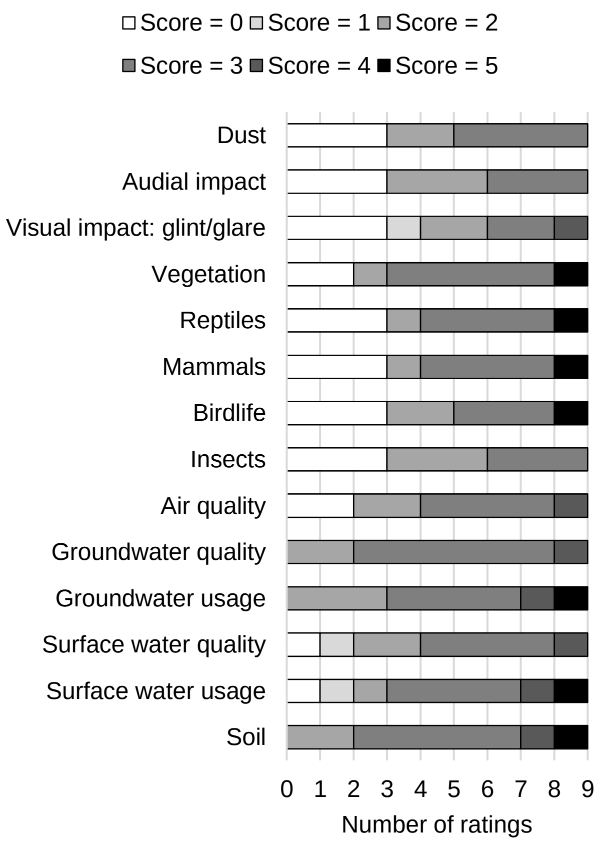


Figure S.5 Ratings for physical scale of impacts on different biophysical elements during shale gas construction.

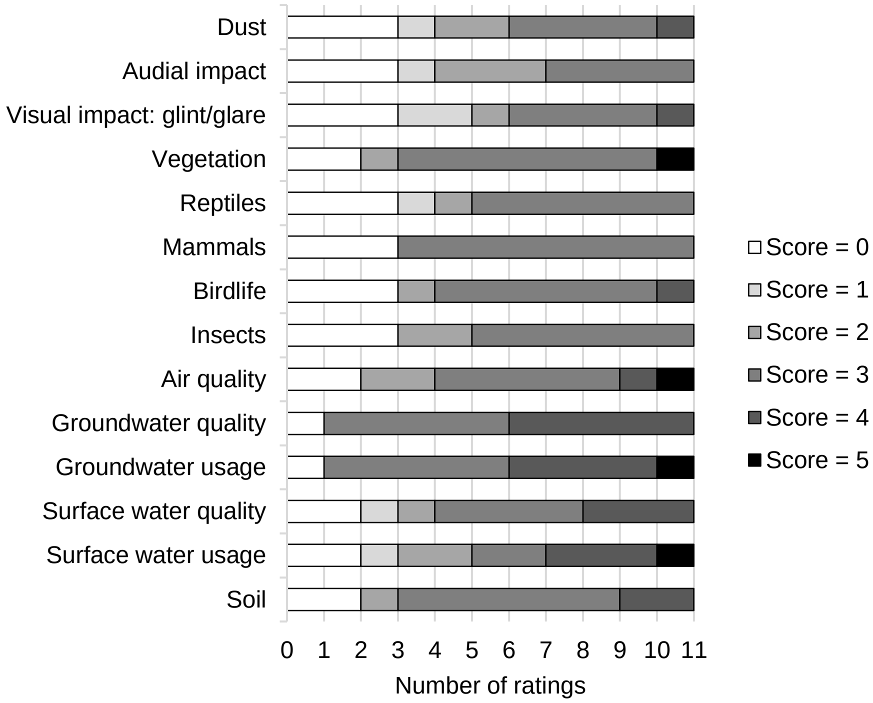


Figure S.6 Ratings for physical scale of impacts on different biophysical elements during shale gas production.

Table S.2 Number of ratings summarised per numerical score value for impact physical scale on biophysical elements during shale gas exploration, construction and production.

Biophysical elements	Exploration						Construction						Production					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Soil	1	0	6	2	2	0	0	0	2	5	1	1	2	0	1	6	2	0
Surface water usage	2	1	4	3	1	0	1	1	1	4	1	1	2	1	2	2	3	1
Surface water quality	2	1	3	4	1	0	1	1	2	4	1	0	2	1	1	4	3	0
Groundwater usage	1	0	6	3	0	1	0	0	3	4	1	1	1	0	0	5	4	1
Groundwater quality	1	0	5	4	1	0	0	0	2	6	1	0	1	0	0	5	5	0
Air quality	2	1	5	2	1	0	2	0	2	4	1	0	2	0	2	5	1	1
Insects	3	0	5	3	0	0	3	0	3	3	0	0	3	0	2	6	0	0
Birdlife	3	0	4	4	0	0	3	0	2	3	0	1	3	0	1	6	1	0
Mammals	3	0	4	4	0	0	3	0	1	4	0	1	3	0	0	8	0	0
Reptiles	3	0	4	4	0	0	3	0	1	4	0	1	3	1	1	6	0	0
Vegetation	2	0	4	4	0	1	2	0	1	5	0	1	2	0	1	7	0	1
Visual impact: glint/glare	3	1	4	3	0	0	3	1	2	2	1	0	3	2	1	4	1	0
Audial impact	3	0	6	2	0	0	3	0	3	3	0	0	3	1	3	4	0	0
Dust	3	0	6	1	1	0	3	0	2	4	0	0	3	1	2	4	1	0

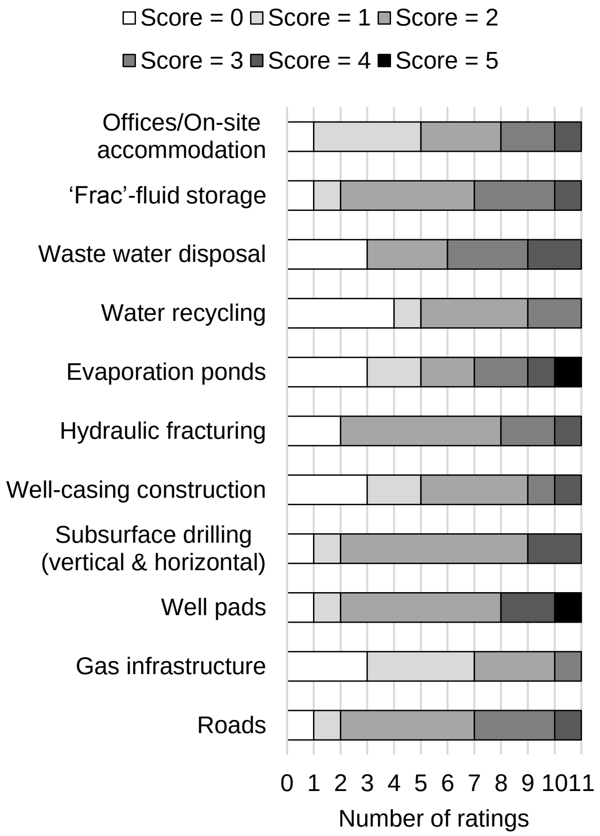


Figure S.7 Ratings for severity of impacts by different infrastructure components during shale gas exploration.

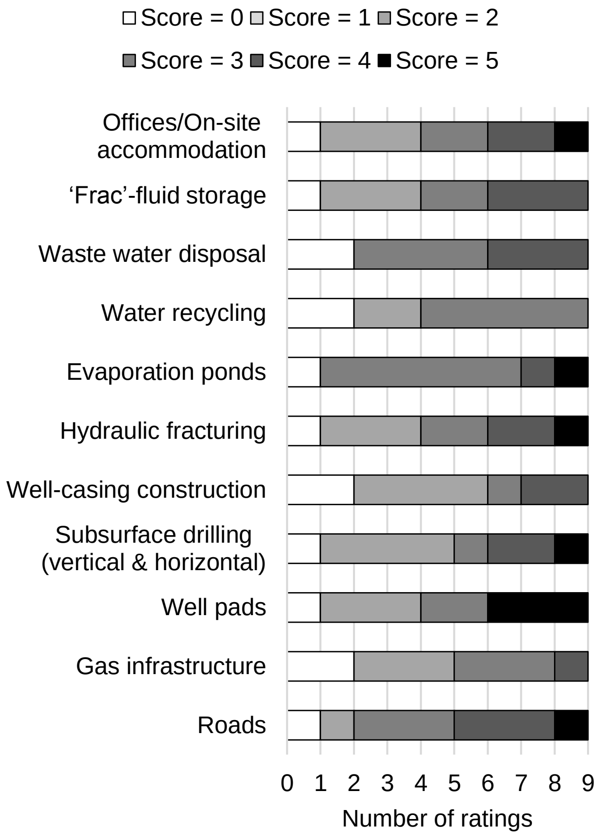


Figure S.8 Ratings for severity of impacts by different infrastructure components during shale gas construction.

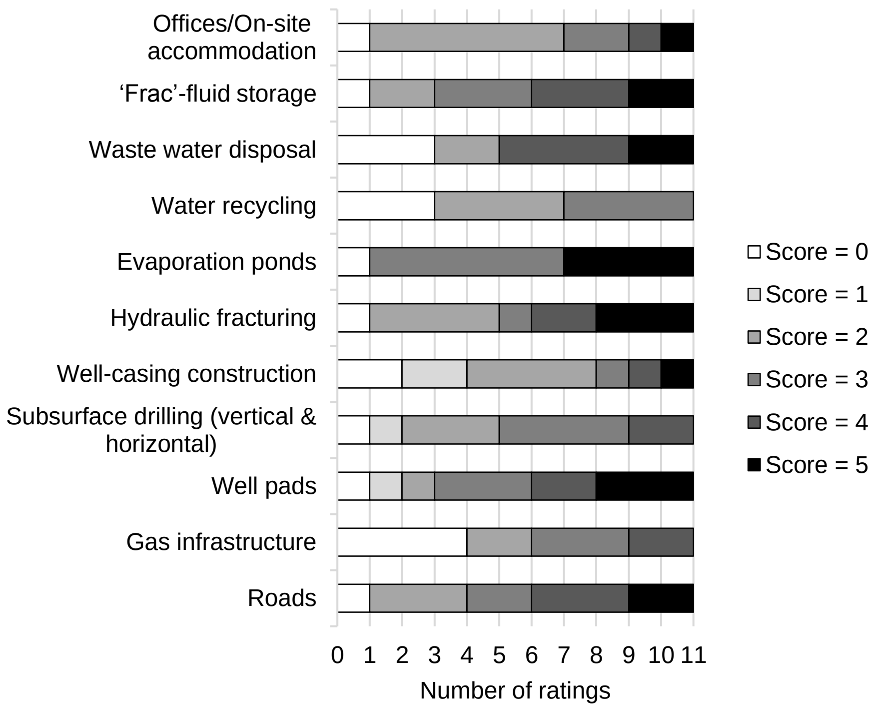


Figure S.9 Ratings for severity of impacts by different infrastructure components during shale gas production.

Table S.3 Number of ratings summarised per numerical score value for severity of impacts by infrastructure components during shale gas exploration, construction and production.

Infrastructure components	**Exploration**						**Construction**						**Production**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Roads	1	1	5	3	1	0	1	0	1	3	3	1	1	0	3	2	3	2
Gas infrastructure	3	4	3	1	0	0	2	0	3	3	1	0	4	0	2	3	2	0
Well pads	1	1	6	0	2	1	1	0	3	2	0	3	1	1	1	3	2	3
Subsurface drilling (vertical & horizontal)	1	1	7	0	2	0	1	0	4	1	2	1	1	1	3	4	2	0
Well-casing construction	3	2	4	1	1	0	2	0	4	1	2	0	2	2	4	1	1	1
Hydraulic fracturing	2	0	6	2	1	0	1	0	3	2	2	1	1	0	4	1	2	3
Evaporation ponds	3	2	2	2	1	1	1	0	0	6	1	1	1	0	0	6	0	4
Water recycling	4	1	4	2	0	0	2	0	2	5	0	0	3	0	4	4	0	0
Waste water disposal	3	0	3	3	2	0	2	0	0	4	3	0	3	0	2	0	4	2
'Frac'-fluid storage	1	1	5	3	1	0	1	0	3	2	3	0	1	0	2	3	3	2
Offices/On-site accommodation	1	4	3	2	1	0	1	0	3	2	2	1	1	0	6	2	1	1

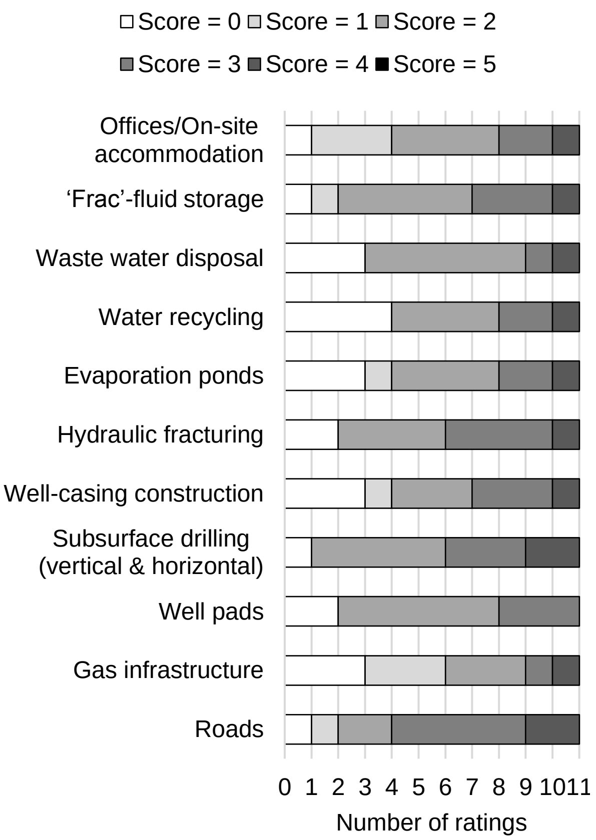


Figure S.10 Ratings for physical scale of impacts by different infrastructure components during shale gas exploration.

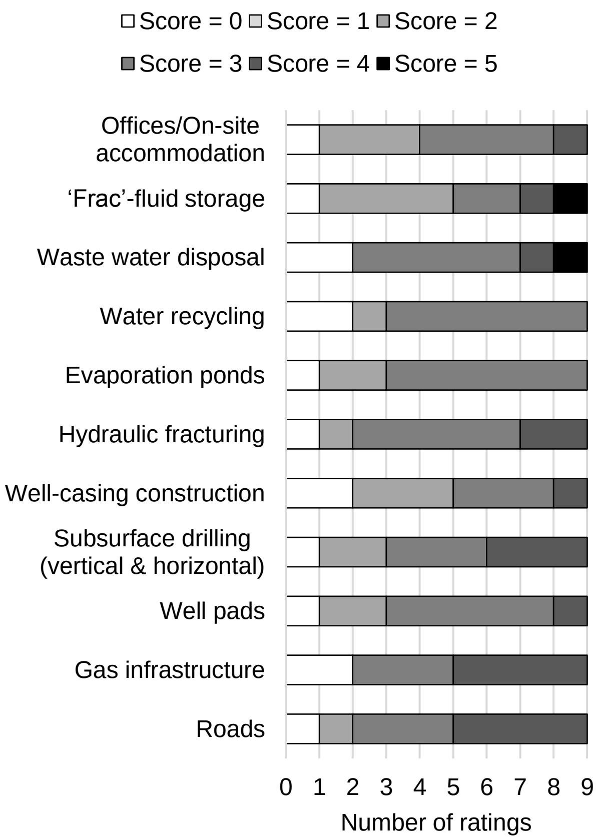


Figure S.11 Ratings for physical scale of impacts by different infrastructure components during shale gas construction.

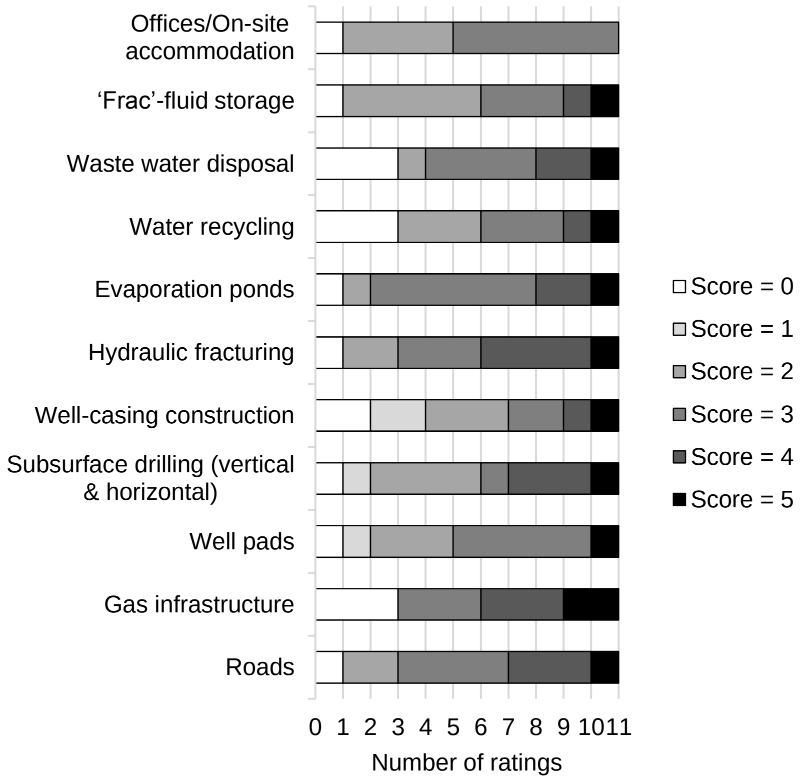


Figure S.12 Ratings for physical scale of impacts by different infrastructure components during shale gas production.

Table S.4 Number of ratings summarised per numerical score value for physical scale of impacts by infrastructure components during shale gas exploration, construction and production.

Infrastructure components	**Exploration**						**Construction**						**Production**					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Roads	1	1	2	5	2	0	1	0	1	3	4	0	1	0	2	4	3	1
Gas infrastructure	3	3	3	1	1	0	2	0	0	3	4	0	3	0	0	3	3	2
Well pads	2	0	6	3	0	0	1	0	2	5	1	0	1	1	3	5	0	1
Subsurface drilling (vertical & horizontal)	1	0	5	3	2	0	1	0	2	3	3	0	1	1	4	1	3	1
Well-casing construction	3	1	3	3	1	0	2	0	3	3	1	0	2	2	3	2	1	1
Hydraulic fracturing	2	0	4	4	1	0	1	0	1	5	2	0	1	0	2	3	4	1
Evaporation ponds	3	1	4	2	1	0	1	0	2	6	0	0	1	0	1	6	2	1
Water recycling	4	0	4	2	1	0	2	0	1	6	0	0	3	0	3	3	1	1
Waste water disposal	3	0	6	1	1	0	2	0	0	5	1	1	3	0	1	4	2	1
'Frac'-fluid storage	1	1	5	3	1	0	1	0	4	2	1	1	1	0	5	3	1	1
Offices/On-site accommodation	1	3	4	2	1	0	1	0	3	4	1	0	1	0	4	6	0	0

T. INTERVIEW RESPONSES OUTSIDE SCOPE OF STUDY FOR SHALE GAS

Table T.1 A summary of the responses which were recorded on the potential impact of shale gas which were not in scope of the thesis.

Socio-economic impacts mentioned

Code	Number of quotations
Additional infrastructure planning challenges	1
Additional socio-economic challenges in local communities	4
Could be linked to increase earthquakes	3
Economic impact	1
Electromagnetic interference/Radio-frequency interference	1
Human/political capacity for weighing up impacts and benefits questionable	3
Impact on Agriculture	1
Impacts on biodiversity due to influx of humans	1
Impacts on sense of place	2
Impacts on tourism	1
Influx of derogatory social services	1
Influx of work seekers	2
National energy planning	1
Overall environmental impact might not be worth economic gain	1
Political corruption	1

Non-direct environmental impacts mentioned

Code	Number of quotations
Competition for water resources	1
Mining of rare earth elements	1
Recycling and end-of-life challenges	5
Residual waste after decommissioning	1
Risk of large areas of land being contaminated	1
Risk of well failure after closure	1
SA/Karoo too water scarce	3

U. ADDITIONAL SPATIAL RESULTS FOR SHALE GAS DEVELOPMENT

Table U.1 A summary of the areas within the study area per vegetation type for vegetation types with >5% proportion of the total study area. The proportion of the vegetation type in the study area and the associated biome is also indicated.

Vegetation type	Total area within study area (km^2)	Percentage of study area represented	Associated biome
Eastern Upper Karoo	37351.7	29.96%	Nama-Karoo
Gamka Karoo	16100.1	12.91%	Nama-Karoo
Western Upper Karoo	15423.1	12.37%	Nama-Karoo
Upper Karoo Hardeveld	7055.9	5.66%	Nama-Karoo
Eastern Lower Karoo	6922.4	5.55%	Nama-Karoo
Karoo Escarpment Grassland	6661.2	5.34%	Grassland

Table U.2 The total lengths of tributaries from the seven river catchment areas which fall within the shale gas exploration area.

River catchment area	Dry (km)	Non-Perennial (km)	Perennial (km)	Unknown (km)	Total (km)	Percentage catchment in exploration area
Orange River	185.9	5071.7	1339.2	105.4	6702.2	12.7%
Great Fish River	-	2906.3	1009.6	259.6	4175.5	72.7%
Gamtoos River	31.1	3237.5	55.4	134.6	3458.6	57.3%
Gourits River	-	2293.6	50.8	0.7	2345.1	30.6%
Sundays River	-	1937.7	65.3	7.8	2010.8	54.3%
Olifants River	4.6	888.5	8.7	-	901.8	12.0%
Great Kei River	-	229.3	15.9	19.1	264.3	5.8%
Totals	**221.6**	**16564.6**	**2544.9**	**527.2**	**19858.3**	**22.5%**

V. MEAN ANNUAL PRECIPITATION FOR SHALE GAS STUDY AREA

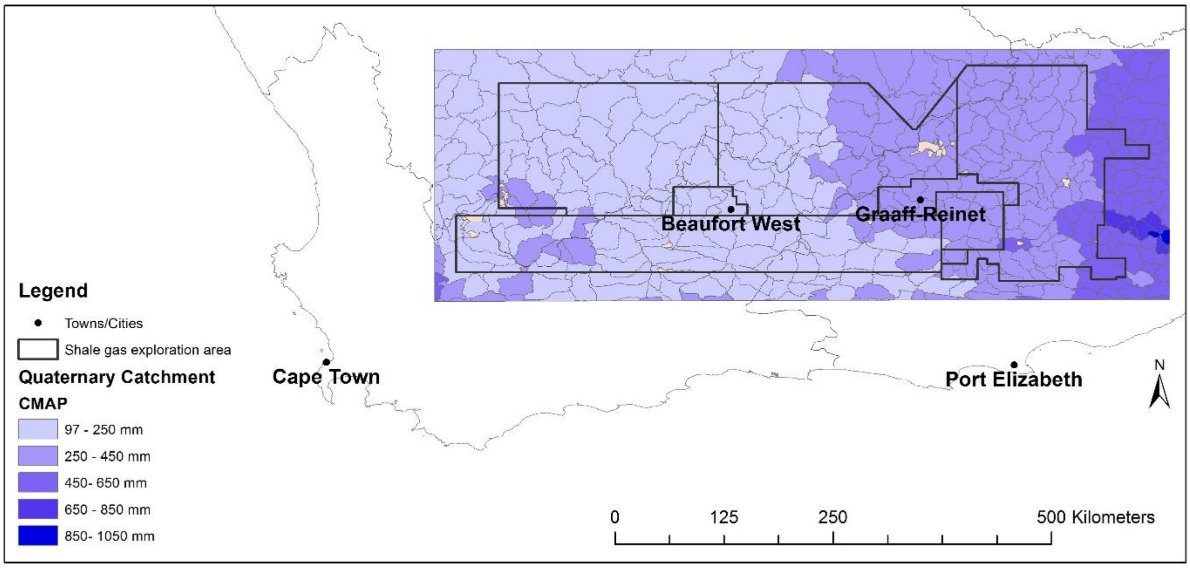


Figure V.1 A map showing the mean annual precipitation per quaternary catchment area within the shale gas exploration areas and SEASGD study area (Department of Water Affairs and Forestry 2012).

W. LINKS TO SHALE GAS AND SOLAR POWER GUIDELINES AND REGULATIONS

Guidelines to minimise the impact on birds of Solar Facilities and Associated Infrastructure in South Africa by BirdLife South Africa: http://www.birdlife.org.za/conservation/terrestrial-bird-conservation/birds-and-renewable-energy

Mineral and Petroleum Resources Development Act, 2002 (Act no. 28 of 2002) Regulations for Petroleum Exploration and Production: http://www.gov.za/sites/www.gov.za/files/38855_rg10444_gon466.pdf

X. ACTIVITIES GOVERNED BY THE REGULATIONS FOR PETROLEUM EXPLORATION AND PRODUCTION (ACT NO. 28 OF 2002)

Table X.1 A summary of the chapter titles included in the Shale Gas Regulations under the Mineral and Petroleum Resources Development Act (Act no. 28 of 2002).

Chapter	Title	Activities / Sub-sections
6	GENERAL PROVISIONS	Definitions Purposes and application of Regulations
7	ENVIRONMENTAL IMPACT ASSESSMENT	Environmental Impact Assessment Assessment of Conditions Below Ground Water Resource Monitoring Assessment of Related Seismicity Site Preparation Site Containment Protection of Astronomy Activities: Radio Astronomy Optical Astronomy
8	WELL DESIGN AND CONSTRUCTION	Well Risk Identification and Assessment Well Design Well Casing Standards Conductor Casing Surface Casing Intermediate Casing Production Casing Centralisers Cement Requirements and Compressive Tests Casing String Tests Formation Pressure Integrity Tests Blowout Prevention Pressure Testing of the Blowout Prevention Equipment Well Examination
9	OPERATIONS AND MANAGEMENT	Management of Operations Drilling Fluids Management of Hydraulic Fracturing: • General • Hydraulic Fracturing Equipment • Mechanical Integrity Tests and Monitoring • Hydraulic Fracturing Fluid Disclosure • Fracture and Fracturing Fluid Containment • Fracturing Fluids Management • Management of Flowback and Produced Fluids • Transportation of Fluids • Fluids Storage • Hydraulic Fracturing Operations • Post Hydraulic Fracturing Report • Management of Water

		Water Balances • Protection of Water Resources • Storm Water Management and Control • Water Use Management of Waste • General • Waste Management Management of Pollution Incidents • Management of Spillage Management of Air Quality • Fugitive Emissions • Fugitive Dust • Noise Control
10	WELL SUSPENSION AND DECOMMISSIONING	Well suspension Suspended Well Integrity Management Well Abandonment/Closure

Y. POLICY BRIEF: THE ENVIRONMENTAL IMPACTS OF ENERGY DEVELOPMENTS IN TWO ARID BIOMES OF SOUTH AFRICA

Based on a Master's study by Justine Rudman titled "Investigating the direct environmental impacts of emerging solar power and shale gas developments in two arid biomes of South Africa. This study was registered at the Department of Conservation Ecology and Entomology with collaboration and support from the Solar Thermal Energy Research Group in the Department of Mechanical and Mechatronic Engineering, both at Stellenbosch University.

Background

The diversification of South Africa's energy system is inviting to alternative energy sources which include renewable and unconventional hydrocarbon resources. Following the launch of the Renewable Energy Independent Power Producer's procurement programme in 2011, the number of solar power developments has increased significantly. Both concentrating solar power (CSP) and photovoltaic (PV) developments are largely located across the central- to north-western interior of the country which coincides with the location of the Nama-Karoo and Savanna biomes[1]. The Karoo Basin, traversing large parts of Kwa-Zulu Natal, Eastern, Northern and Western Cape, is estimated to hold approximately 300 trillion cubic feet of shale gas. However, no exploration activities have commenced to confirm the size of the shale gas resource. Figure 1 shows the location of solar power environmental impact assessments (EIAs) and areas which shale gas exploration applications have been received with respect to the distribution of the biomes of South Africa.

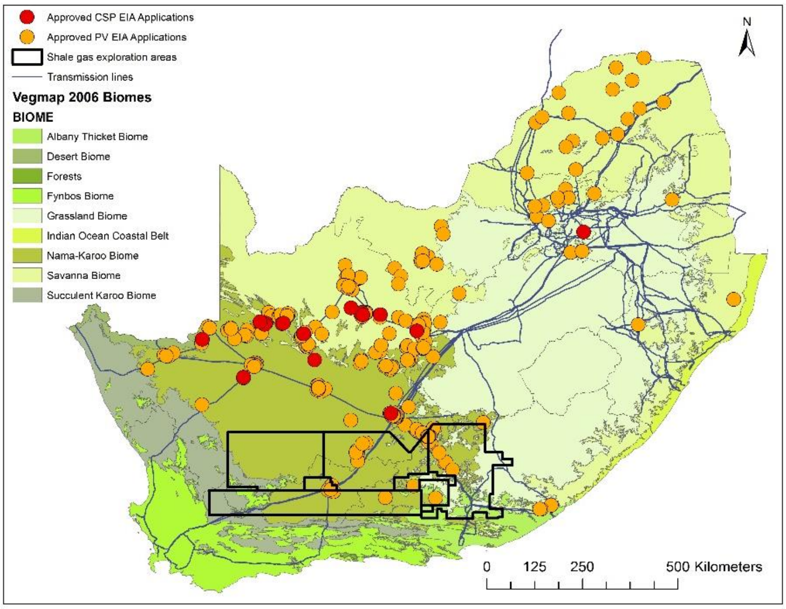


Figure Y.2 A biome map of South Africa showing the location of EIAs approved for solar power developments and the shale gas exploration area (SANBI 2012).

The environmental impacts of solar power developments are being assessed through EIAs and regulated by the Department of Environmental Affairs. Those impacts associated with shale gas development activities are also planned to be assessed by EIAs, but regulated by the Department of Mineral Resources. EIAs are being done for individual projects, but do not investigate the possible cumulative impacts on biophysical components arising from the distribution of multiple projects across the landscape. In light in the increasing number of solar power projects in South Africa and the planned commencement of shale gas development, such cumulative impacts could imply widespread land use change and challenges to natural resource planning and management in the Savanna and Nama-Karoo biomes.

This initial investigation of the direct environmental impacts of emerging solar power and shale gas developments in two arid biomes represents a first of its kind in South Africa and was conducted through a mixed-method approach. The data collection and analysis included structured interviews with experts, site visits to solar power developments and spatial analysis by using spatial datasets. The findings provided a valuable understanding of the direct environmental impacts of existing solar power developments and that which can be expected from shale gas development. A summary of the findings and recommendations are presented here with the aim to inform policy and regulation relevant to such environmental impacts.

[1] A broad ecological unit having similar vegetation structure and exposed to similar macroclimatic patterns, often linked to characteristic levels of disturbance such as grazing and fire (Mucina & Rutherford 2006; Low & Rebelo 1998).

Findings – direct environmental impacts

Findings regarding the most significant impacts associated with energy developments:

Solar power

- The impacts on avifauna and habitat transformation were identified as the most significant impacts associated with solar power developments.
- Approximately 70% solar power developments selected as preferred bidders through the first three rounds of the REIPPPP are located within the Nama-Karoo and 23% in the Savanna biome. The total area occupied by CSP and PV developments is circa 998 km^2.
- Interviewees suggested that the outcomes of the Strategic Environmental Assessment (SEA) for wind and PV are not used and that the process can be improved. This was supported by the spatial analysis confirming that only 15% of PV developments are located within the PV Renewable Energy Development Zones identified through the Wind and Solar PV SEA.

Shale gas

- Quality and quantity impacts on water resources in an already water-stressed environment together with cumulative environmental impacts were identified as the most concerning related to shale gas development.
- Seven major river catchment areas fall within the shale gas exploration area.
- The Nama-Karoo biome is the most affected by shale gas developments and makes up approximately 68% of the shale gas exploration area.
- To completely understand and study the expected direct environmental impacts of shale gas development in the Nama-Karoo, the receiving environment's baseline need to be known. However, uncertainty related to these baseline conditions and the planned location of shale gas activities were highlighted as an overarching concern as it makes studying the severity of direct environmental impacts.

Findings – EIA process and management of impacts

Findings on the sufficiency of the EIA process and management of energy development impacts:

Solar power

- The majority of interviewees (55%) agreed that the current EIA process is sufficient to capture all impacts related to solar power developments. However, the EIA process should be implemented by competent environmental assessment practitioners (EAPs) and cumulative impacts must be included in the process.
- The transition between EIAs and the follow-up management plans and systems throughout the lifespan of a solar power project was highlighted as an area of weakness due to the shift in responsibilities between the environmental assessment company, developer and designated competent authority.

Shale gas

- The majority of interviewees (53%) think that the current EIA process is sufficient to capture all possible impacts from shale gas development. These responses were supported by similar comments as were received for solar power, i.e. that the process needs to be sufficiently implemented and should include cumulative impacts.
- Several specific impacts were mentioned as being not sufficiently covered in the current EIA process; these include groundwater contamination, well abandonment, wastewater treatment and long-term impact.

Recommendations

- For both solar power and shale gas, cumulative impacts arising from a network of developments (i.e., power plants and shale gas well pads connected by roads, powerlines or gas infrastructure) need to be studied and planned for from a strategic perspective.
- Coordination is needed at a national level to guide the EIA process and the various roles and responsibilities which arise from the different management programmes and plans from commencement throughout the project lifespan. This is particularly relevant for shale gas development
- Incentives and/or regulations should be put in place to monitor impacts and the collection of impact data. This data should be used to feed back into a strategic planning process which takes the cumulative impacts arising from numerous projects. This would assist with the identification of impacts in future developments as well as informing management strategies.

References

Low, A.B. & Rebelo, A.G. eds., 1998. Vegetation of South Africa, Lesotho and Swaziland Second., Pretoria: Department of Environmental Affairs and Tourism.

Mucina, L. & Rutherford, M.C. eds., 2006. *The vegetation of South Africa*, South African National Biodiversity Institute, Pretoria.

South African National Biodiversity Institute, 2012. National Vegetation map of South Africa 2012. Available at: http://bgis.sanbi.org/SpatialDataset/Detail/595.