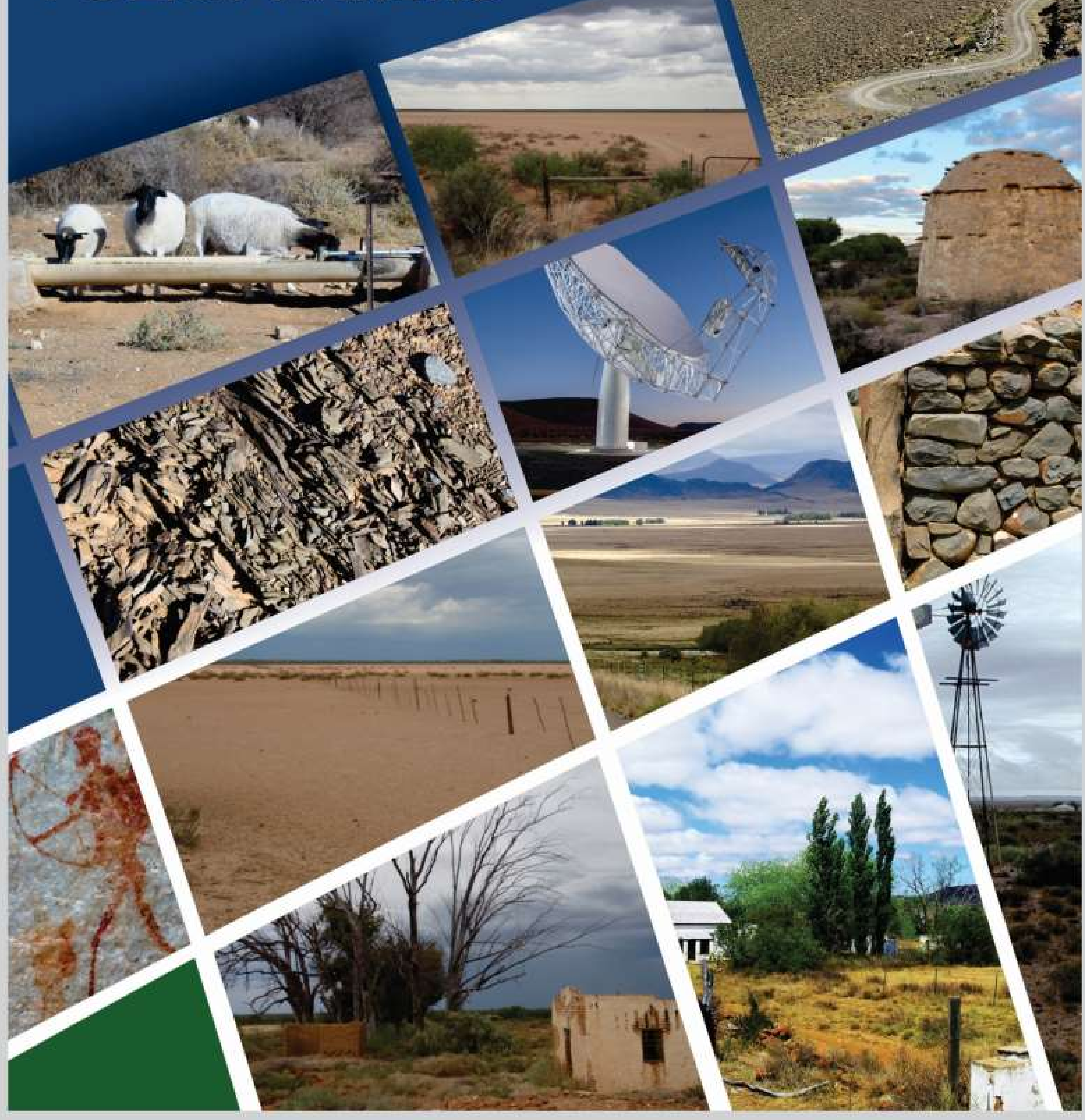
Shale Gas Development in the Central Karoo:

A Scientific Assessment of the Opportunities and Risks

SUMMARY FOR POLICY MAKERS



Shale Gas Development in the Central Karoo:

A Scientific Assessment of the Opportunities and Risks

SUMMARY FOR POLICY-MAKERS

(Second Edition, republished 09 June 2017)

Edited by Bob Scholes, Paul Lochner, Greg Schreiner,
Luanita Snyman-Van der Walt and Megan de Jager

Authors

Selwyn Adams, Graham Alexander, John Almond, Katye Altieri, Megan Anderson, Emma Archer van Garderen, Doreen Atkinson, Karin Badenhorst, Dave Baldwin, Oliver Barker, Corinna Bazelet, Stephen Berrisford, Roger Bills, Tobias Bischoff-Niemz, Christy Bragg, Bill Branch, Peter Bruyns, Michael Burns, Clinton Carter-Brown, Albert Chakona, Matthew Child, Simon Clarke, Nicholas Clarke, Ralph Vincent Clarke, Henk Coetzee, Andrew Coetzer, Willem Coetzer, Jonathan Colville, Werner Conradie, Fahiema Daniels, Claire Davis, Elizabeth (Liz) Day, Jenny Day, Megan de Jager, Michael de Jongh, Richard Dean, Moctar Doucouré, Amanda Driver, Gerrie du Rand, Justin du Toit, Katie du Toit, Raymond Durrheim, Connal Eardley, Ismail Ebrahim, Dave Edge, Surina Esterhuyse, Justine Ewart-Smith, Saliem Fakir, Roger Fisher, Rebecca Garland, Dave Gaynor, Simon Gear, Caroline Gelderblom, Bettina Genthe, Cheri Green, Simon Hall, Michelle Hamer, Dai Herbert, Philip Hobbs, Danita Hohne, Stephen Holness, Liana Jansen, Adrian Jongens, Marthie Kemp, Mahlatse Kgatla, James Kinghorn, Menno Klapwijk, Gerrit Kornelius, Patricia Kramer, Kedibone Lamula, Quinton Lawson, Given Leballo, Anthony Leiman, Lehman Lindeque, Paul Lochner, Leslie London, Robin Lyle, Judy Maguire, Ashton Maherry, Antonia Malan, Norma Malatji, Mervyn Mansell, Sethulego Matebesi, Dave McKelly, Ian McLachlan †, Matthew Meas, Silvia Mecenero, John Midgley, Vunganai Midzi, Jolynn Minnaar, Musa Mlambo, David Morris, Muvhuso Mosetsho, Zainab Mowzer, Hlengiwe Mtshali, Bernard Oberholzer, Suzan Oelofse, Noel Oettlé, Mark Oranje, Jayson Orton, Anthony Osler, Braam Otto, Phil Paige-Green, Louwrens Pretorius, Domitilla Raimondo, Nick Rivers-Moore, Peter Rosewarne, Nigel Rossouw, Hanna-Andrea Rother, Melville Saayman, Igshaan Samuels, Catherine Schenk, Bob Scholes, Johan Schoonraad, Greg Schreiner, Roland Schulze, Leanne Seeliger, John Simaika, Andrew Skowno, Kate Snaddon, Luanita Snyman-Van der Walt, Barry Standish, Herman Staude, Maronel Steyn, Adrian Tiplady, Simon Todd, Daan Toerien, Krystal Tolley, Ikechukwu Umejesi, Les Underhill, Dewidine van der Colff, Paul van der Merwe, Elsona van Huyssteen, Wikus van Niekerk, Simon van Noort, Lize von Staden, Hugo van Zyl, Susi Vetter, Andrew Wade, Mieke Willems, Harald Winkler, Jarrad Wright, Graham Young, Owen Zinaman

CONTENTS

Tables

Figures

Boxes

THE ORIGIN, PURPOSE AND METHOD OF THIS ASSESSMENT

The potential economic and energy security opportunities of a medium to large shale gas resource could be substantial for South Africa; as are both the potential social and environmental risks associated with a domestic gas industry in the Central Karoo. The development of shale gas using vertical and horizontal drilling and hydraulic fracturing or 'fracking' technologies, has been presented to the South African public and decision makers as a trade-off between economic opportunity and environmental protection. As such, it has become a highly divisive topic in South Africa, but one which has been, up to now, poorly informed by publically-available evidence.

To address this lack of critically-evaluated information, a 'scientific assessment' was commissioned, guided by the principles of *saliency*, *legitimacy* and *credibility* (see Preface, Scholes et al. 2016). The 18 Chapters of the scientific assessment were drafted by 146 authors and peer reviewed by a further 25 local and 46 international independent peer review experts, and by a large number of stakeholders involved in the process. The key objective of the scientific assessment is to provide society with an evidence base, at a strategic level, which will assist South Africa in developing a better understanding of the risks and opportunities associated with SGD, if it occurs in South Africa. The geographical scope of the scientific assessment study area is provided in Figure SPM 0.2.

The Summary for Policy-Makers (SPM) is a concise compendium of the key findings of the scientific assessment[1]. The methodology for the assessment is based on the concept of 'risk', but this does not mean that the opportunities associated with SGD are not also assessed in a balanced fashion. The SPM begins with Chapter 1 (Burns et al., 2016) which provides, in as much detail as feasible, the scale and type of activities which would logically be associated with three SGD scenarios; measured against a Reference Case scenario, where no SGD takes place. This includes introductory text explaining the current understanding of the petroleum geology of the Central Karoo.

Based on the information contained in Chapter 1, Chapters 2-18 undertake a rigorous and systematic risk assessment of the impacts relating to SGD based on a transparent expert judgement process. This allows for the consideration all impacts of an issue in a common way and where possible, within a spatial context. Risk is determined by estimating the *likelihood* of impacts occurring, in relation to their *consequences* i.e. *likelihood x consequence = risk* (Figure SPM 0.1). Risk is assessed for each significant impact, on different types of receiving entities e.g. the rural poor, a sensitive wetland, important heritage feature etc. It is qualitatively assessed into the following categories: *undiscernible*,

[1] The symbol '§', which is located at the end of concluding statements or paragraphs in the SPM, denotes the location of the Chapter and sub-section where the evidentiary base for the summary statement/s can be traced to the specific reference source.

very low, *low*, *moderate*, *high* and *very high.* The risk categories are predefined as a set of criteria which explain the nature and implications of the risk ascribed (Table SPM 0.1). For each topic, consequence levels have been determined by the individual chapter teams across the different disciplinary domains i.e. *slight*, *moderate*, *substantial*, *severe* and *extreme*. This means that all risk categories across the different topics are 'calibrated', which makes them comparable, both conceptually and within a spatial context.

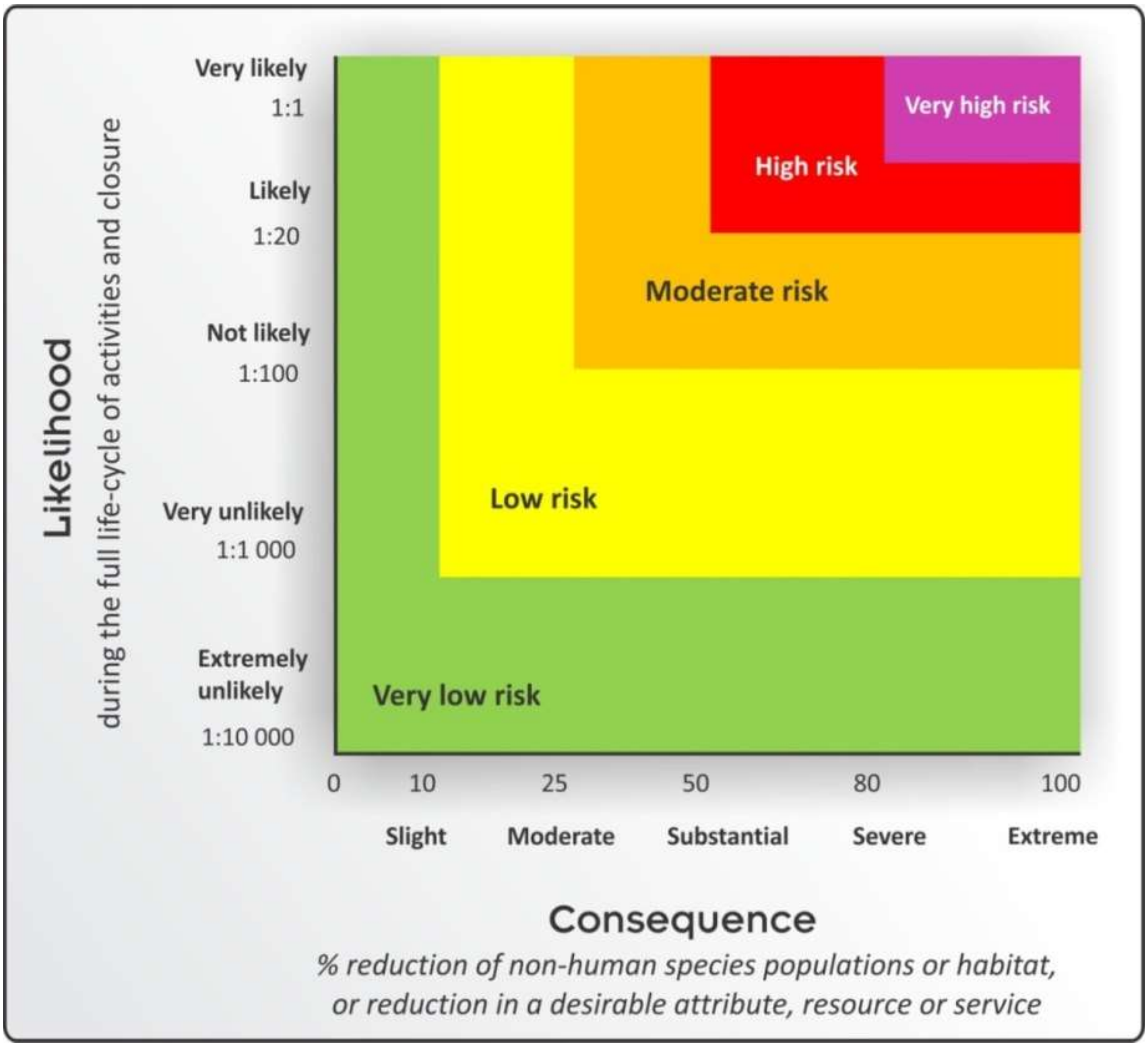


Figure SPM 0.1: Risk assessment diagram showing *likelihood x consequence* to determine risk. Risk is qualitatively measured by multiplying the likelihood of an impact by the severity of the consequences to provide risk rating ranging from very low, low, moderate, high and very high.

Table SPM 0.1: Predefined set of criteria applied across the Chapters of the scientific assessment.

Risk category	Definition
No discernible risk	Any changes that may occur as a result of the impact either reduce the risk or do not change it in a way that can be differentiated from the mean risk experienced in the absence of the impact.
Very low risk	Extremely unlikely (<1 chance in 10 000 of having a consequence of any discernible magnitude); or if more likely than this, then the negative impact is noticeable but slight, i.e. although discernibly beyond the mean experienced in the absence of the impact, it is well within the tolerance or adaptive capacity of the receiving environment (for instance, within the range experienced naturally, or less than 10%); or is transient (< 1 year for near-full recovery).
Low risk	Very unlikely (<1 chance in 100 of having a more than moderate consequence); or if more likely than this, then the impact is of moderate consequence because of one or more of the following considerations: it is highly limited in extent (<1% of the area exposed to the hazard is affected); or short in duration (<3 years), or with low effect on resources or attributes (<25% reduction in species population, resource or attribute utility).
Moderate risk	Not unlikely (1:100 to 1:20 of having a moderate or greater consequence); or if more likely than this, then the consequences are substantial but less than severe, because although an important resource or attribute is impacted, the effect is well below the limit of acceptable change, or lasts for a duration of less than 3 years, or the affected resource or attribute has an equally acceptable and un-impacted substitute.
High risk	Greater than 1 in 20 chance of having a severe consequence (approaching the limit of acceptable change) that persists for >3 years, for a resource or attribute where there may be an affordable and accessible substitute, but which is less acceptable.
Very high risk	Greater than even (1:1) chance of having an extremely negative and very persistent consequence (lasting more than 30 years); greater than the limit of acceptable change, for an important resource or attribute for which there is no acceptable alternative.

What follows in the sections below are the key ‘headline statements’, communicated in a common language, highlighting the most salient opportunities and risks emanating out of the full 18 Chapter assessment. Where appropriate the risk of an impact is provided without and with mitigation, providing the reader with an indication of how the risk profile of an impact changes with adequate mitigation employed. This is also spatially depicted as a composite risk ‘picture’, assessed across the scenarios, without and with mitigation in Section 19.

Figure SPM 0.2: Geographical scope of the scientific assessment study area.

The assessment considers SGD activities originating in a 171 811 km^2 region of the Central Karoo, delimited by the applications for Exploration Rights (for shale gas) which have been lodged by Shell, Falcon and Bundu, plus a 20 km buffer. The assessment follows the consequences of SGD in this region to the point of material impact, even if that is outside the study area – as may be the case of impacts on vectors such as air or water which are not spatially static.

1. THE PRESENCE OF NATURAL GAS IN THE CENTRAL KAROO

1.1 The geology of the Karoo Basin

The Karoo Basin is known to contain natural gas. This geological formation underlies 700 000 km^2 of South Africa (Figure SPM 1.1), including the scientific assessment study area, where ~87% of the surface area comprises sandstones, mudstones and shales of the Beaufort Group. From flat-lying structures in its northern part, the basin deepens and the sedimentary layers thicken towards the south-west, up to its interface with the mountains of the Cape Fold Belt. [§1.3.1]

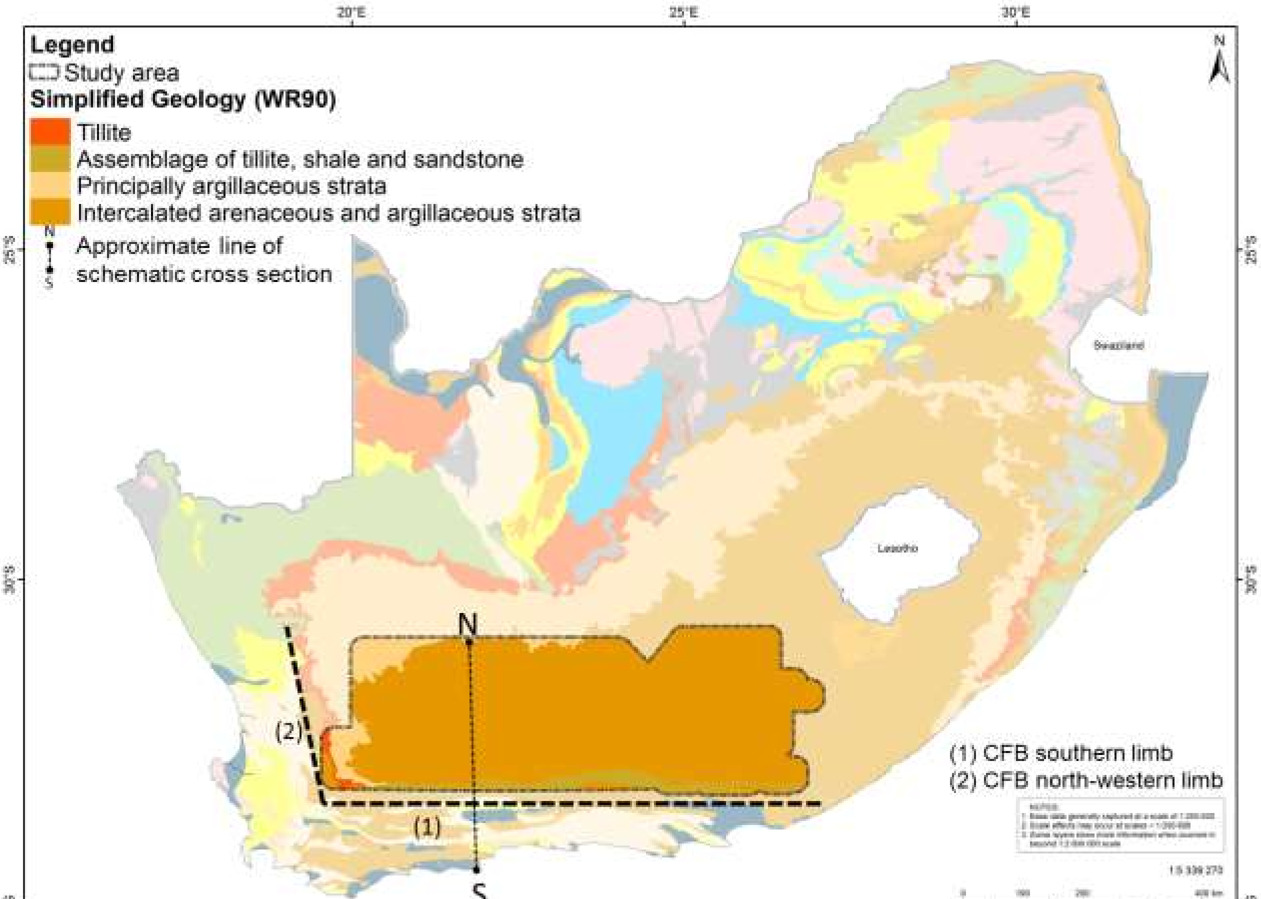


Figure SPM 1.1: Simplified geology of map of South Africa overlayed with the assessment study area. It shows the substantial extent of the main Karoo Basin (light brown areas) deepening from the north-eastern interior to the south-central interior where it abuts against the southern limb of the Cape Fold Belt (CFB); section line S-N through the study area marks the schematic profile in Figure SPM 1.3.

Natural gas in the Karoo Basin is said to be 'unconventional' in that it does not occur in pockets of porous rock (called "reservoirs"), from which it would flow without stimulation if penetrated by a well. Unconventional shale gas occurs as methane trapped in shale formations of low permeability, from which it can only be released by the process of hydraulic fracturing, popularly known as 'fracking' (Figure SPM 1.2). [§1.1]

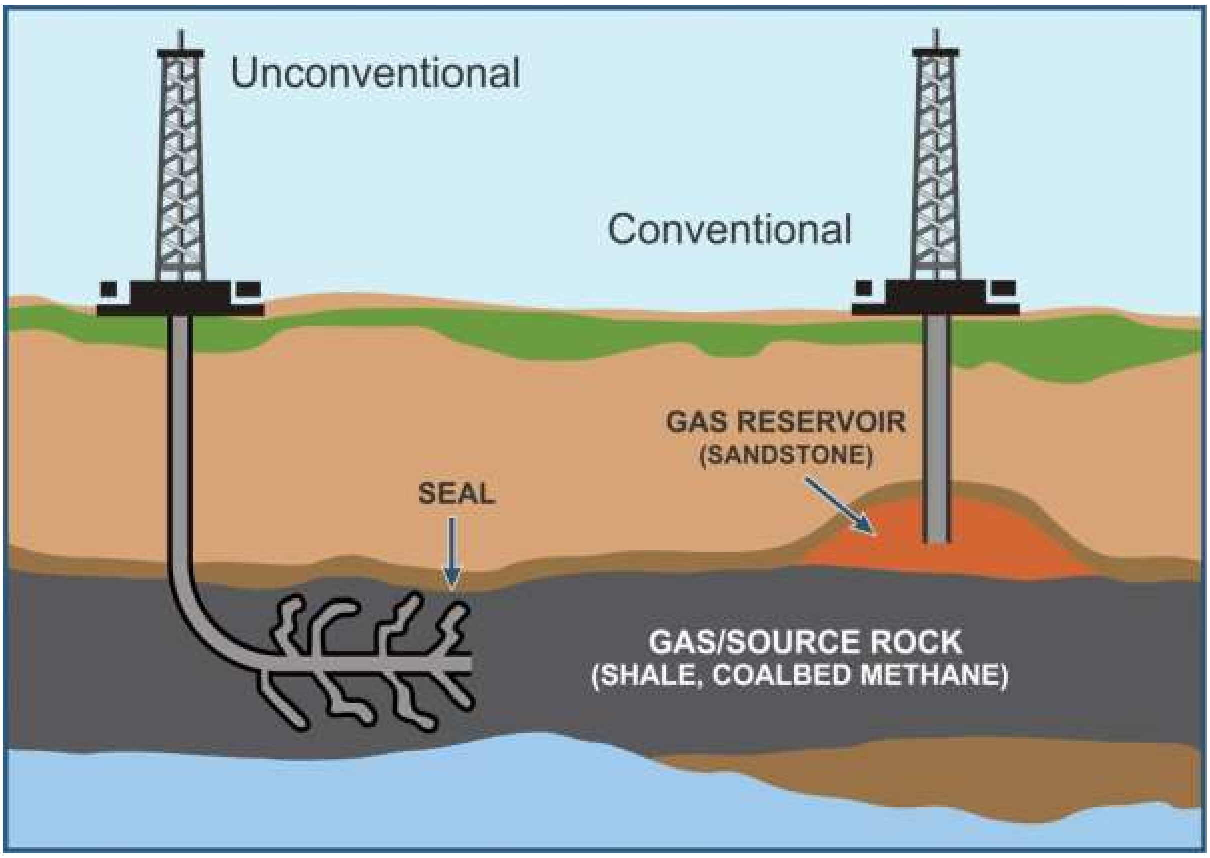


Figure SPM 1.2: Cartoon demonstrating the difference between 'conventional' and 'unconventional' gas reserves.
To extract conventional gas, a hole is drilled into the reservoir and the gas flows out by itself. For unconventional shale gas, such as that which occurs in the Karoo, the source rock lies very deep below the surface. The gas is tightly held and must be released by fracturing the rock around a wellbore, drilled horizontally for a long distance into the gas-containing shale layer
(adapted from http://worldinfo.org/2012/01/point-of-view-unconventional-natural-gas-drilling).

The total quantity of shale gas that occurs within the study area is uncertain, as is where exactly it may be concentrated. There may be no economically extractable gas. Geological upheavals hundreds of millions of years ago, specifically the intrusion of hot lava (dolerite) and the pushing-up of the Cape Fold Mountains are believed to have reduced the volume of gas originally in place. Indications are that remaining gas is most likely concentrated in the area between the Cape Fold Mountains to the south and the doleritic Nuweveld Mountains to the north, and at depths greater than 2 km below the surface (Figure SPM 1.3). [§1.3.1]

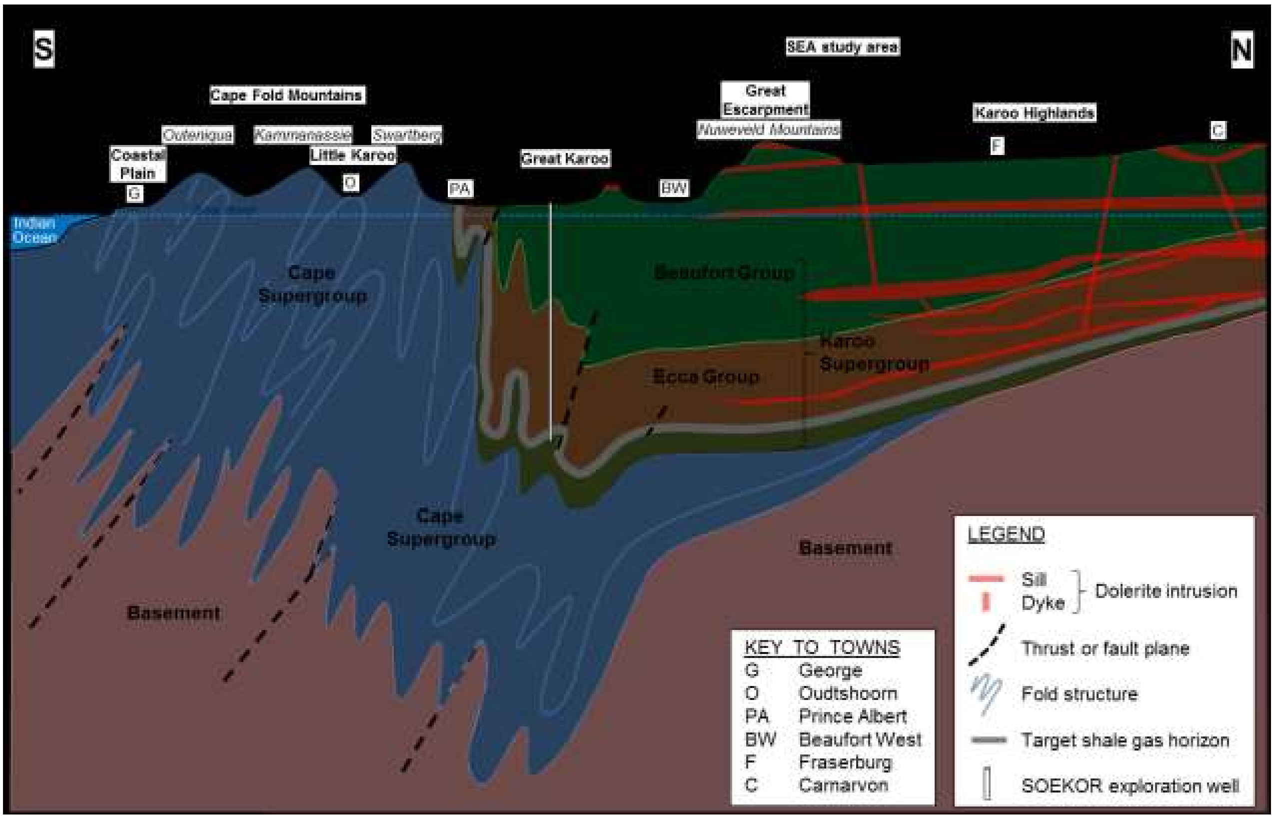


Figure SPM 1.3: Schematic geological profile across the study area.
The profile follows along the S-N section line in Figure SPM 1.1, illustrating the basin-like stratigraphic succession of Karoo Supergroup sedimentary strata in the main Karoo Basin north of the Swartberg Mountains, the Great Escarpment formed by the Nuweveld Mountains, and the underlying Cape Supergroup rocks that pinch out northwards against basement rocks (modified after Rosewarne et al., 2013).

1.2 Stages of shale gas development

SGD entails a broad range of activities which occur in different stages over extended periods of time, at various intensities and each with particular spatial footprints. This assessment covers all the main SGD activities, throughout their lifespan and after they have ceased, for the period during which impacts can be anticipated (Figure SPM 1.4). It addresses associated ‘upstream activities’ such as seismic surveys, wellpad and other site preparations and drilling deep vertical exploration boreholes. The assessment assumes that if initial exploration results are promising, these activities may be followed by deviated drilling to form horizontal wells that penetrate targeted shale layers, which would be ‘fracked’ to determine gas yields. Gas production activities could follow, involving the establishment of a wellfield(s), with repeated drilling and fracking exercises. There are a number of surface activities associated with this, such as waste management and transportation of equipment, materials and personnel to and from areas of operations. The assessment also considers 'downstream activities', focusing on how the produced gas could be used economically. [§1.4.2]

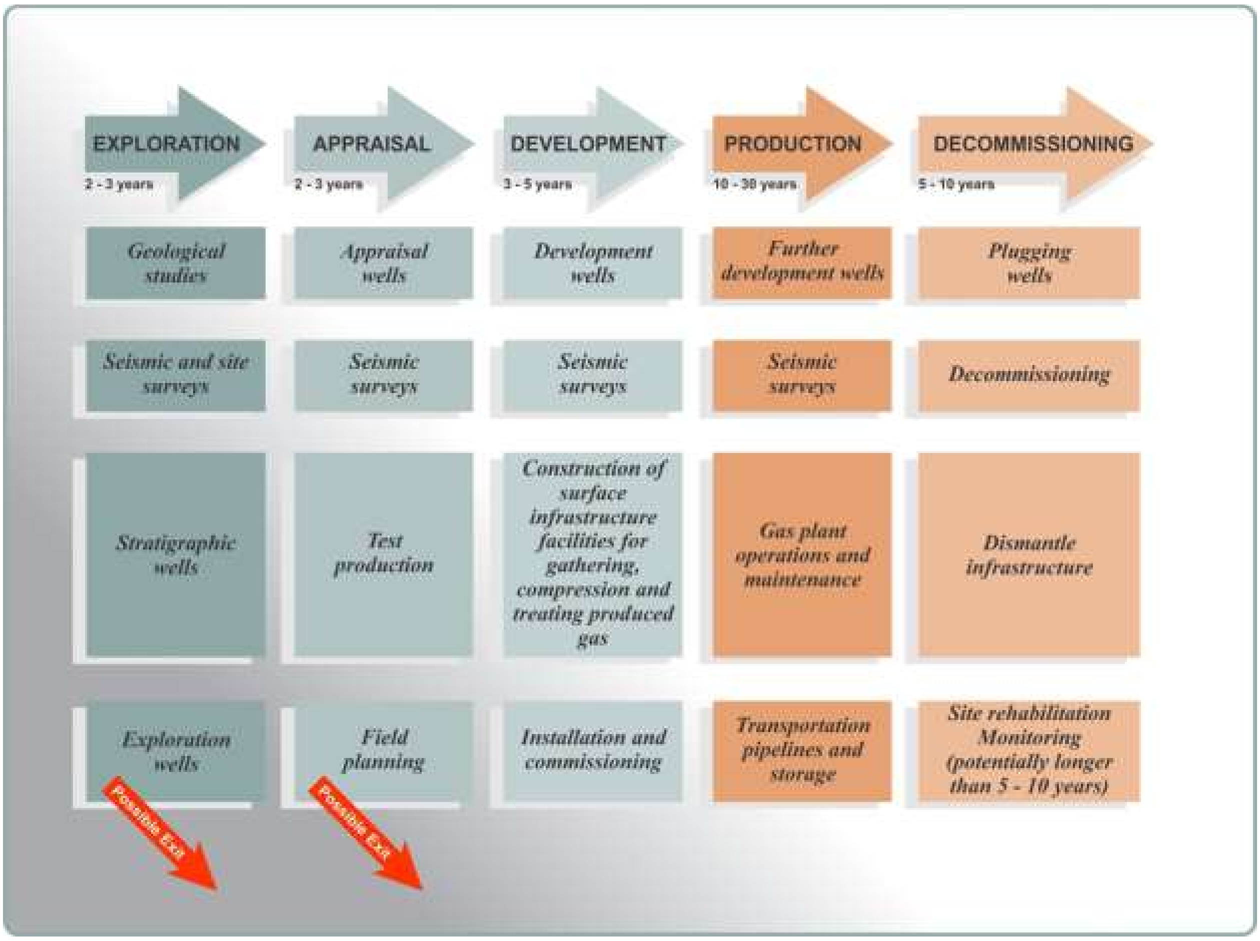


Figure SPM 1.4: Typical life-cycle of a shale gas development programme.
The process diagram shows the stage, timeframes and nature of activities, as well as the possible exit points if gas is not found in sufficient volumes or at flow rates that make production economically unfeasible. Note that this timeline does not account for permitting and regulatory processes that would need to be undertaken in the South African context such as site specific environmental assessments (adapted from National Petroleum Council, 2011).

Exploration is the first stage of the SGD life cycle, but it continues throughout. It is concentrated in the first few years of exploration and then continues into the production stage of the SGD life cycle to guide the location of ongoing drilling and fracking. Exploration involves geological studies, seismic surveys and drilling of vertical stratigraphic wells to obtain geological core samples for analysis. Exploration wells may also yield information on gas concentrations. The appraisal stage follows exploration, and for a single targeted area typically lasts about 2-3 years. It involves drilling appraisal wells, which have vertical and horizontal sections used to penetrate potential gas-yielding shale within the target formation. Appraisal scale fracking is undertaken. Equipment used for drilling and fracking, a range of materials and waste receiving facilities are contained within wellpad areas, each measuring around 2 ha. An area of similar extent to the wellpads is developed for temporary accommodation of drilling crews in the general area of activities. If, during the exploration or appraisal phase, it is revealed that technically recoverable reserves cannot be economically exploited, the wells and surface infrastructure are decommissioned. [§1.4.1]

The production stage of SGD operations might last 10-30 years, probably with the highest level of activity in the first 3-5 years. It involves the development of production wells (and access roads to the wellpads), the establishment of a gas pipeline network to convey produced gas to a central treatment processing, and the export of the treated gas by pipeline for the downstream uses. These would be located within the study area under the Small Gas scenario, or both within and outside the study area under the Big Gas scenario (Section 1.3). Once the production phase terminates, final decommissioning requires a further 5-10 years to be concluded. This involves plugging the wells, dismantling infrastructure and rehabilitating the sites. Monitoring and remediation interventions continue indefinitely. [§1.4.1]

During production, a typical shale gas wellfield occupies an area of about 900 km^2, which contains 50-60 wellpads, each supporting around 10 wellbores. Because the horizontal part of the wellbore extends several kilometres from the vertical part, the wellpads in a production wellfield are typically separated from one another by 3-5 km. While a production wellbore is yielding gas, new wellbores are drilled from the same wellpad, angled in different directions into the gas-containing shale layer. New wells maintain the planned rate of gas production as yields from wells drilled earlier diminishes. Wellpads are accessed by a network of unpaved roads, with the gathering network of buried gas pipelines mostly contained within the road reserves. At the conclusion of various operations, equipment and facilities (the drill rig, temporary structures, storage tanks, pumps, trucks, generators, etc.) are removed from the wellpads (Figure SPM 1.5Figure SPM 1.6). [§1.4.1]

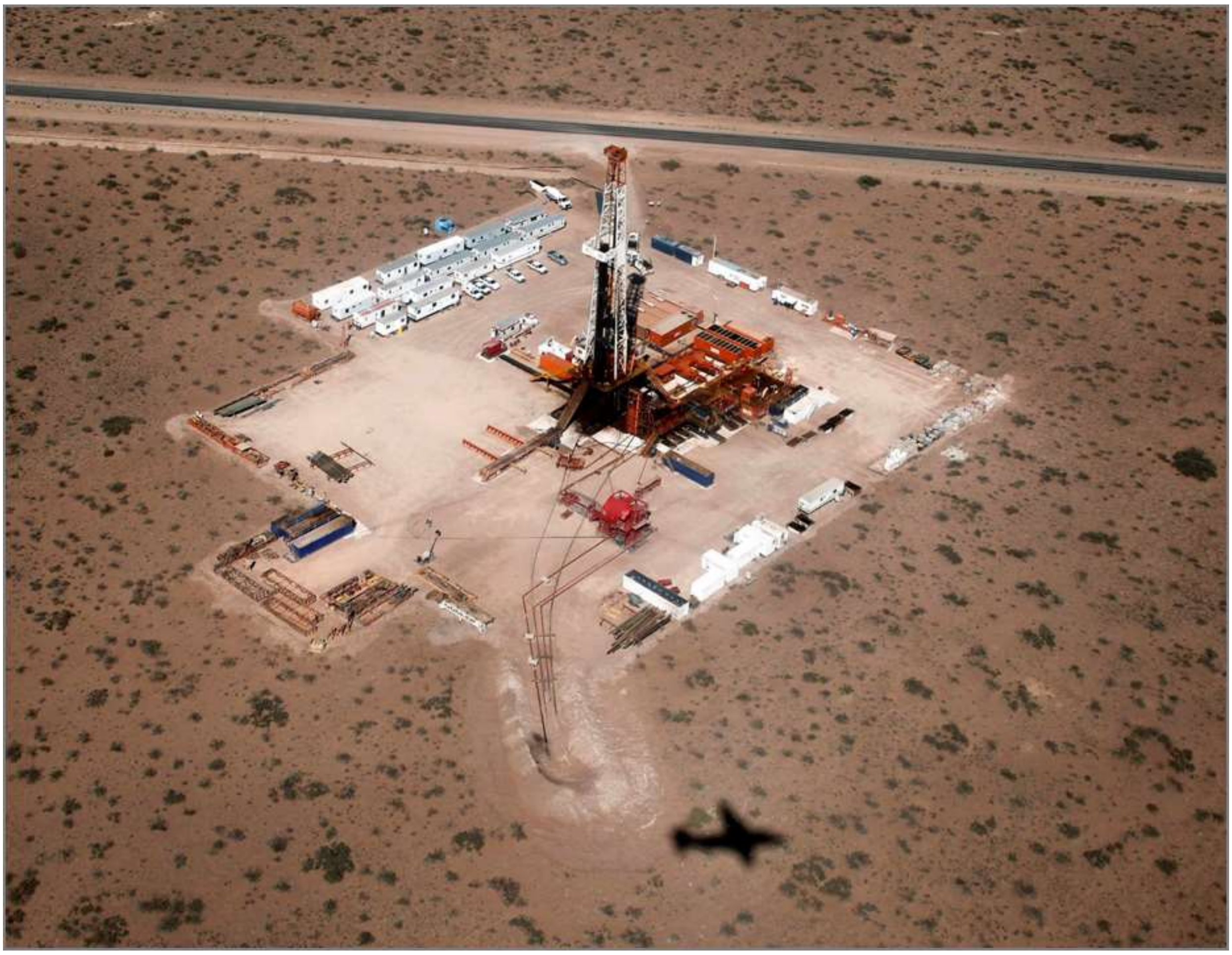


Figure SPM 1.5: Wellpad layout with a drill rig of about 40 m in height within an arid environment in Argentina.
(Source:REUTERS, http://www.vcpost.com/articles/5923/20120925/sidewinder-drilling-to-buy-union-drilling-for-139-mln.htm).

During fracking, 'fracking fluid' is pumped under high pressure into the gas-containing shale layers deep underground, via a horizontal well lined with a perforated steel casing. The high-pressure fluid causes tiny cracks to form in the shale, extending up to a few hundred metres from the well. When the pressure is released and the fracking fluid is pumped back to the surface, gas is released from the fractured shale (Figure SPM 1.7). The gas may flow for several years, at a declining rate.

Figure SPM 1.6: Production wellpad with supporting infrastructure in the United States (see annotations). In terms of current South African legislation, open water storage (impoundment) such as illustrated in this example from North America, would not be permitted. Image sourced from Range Resources Corporation.

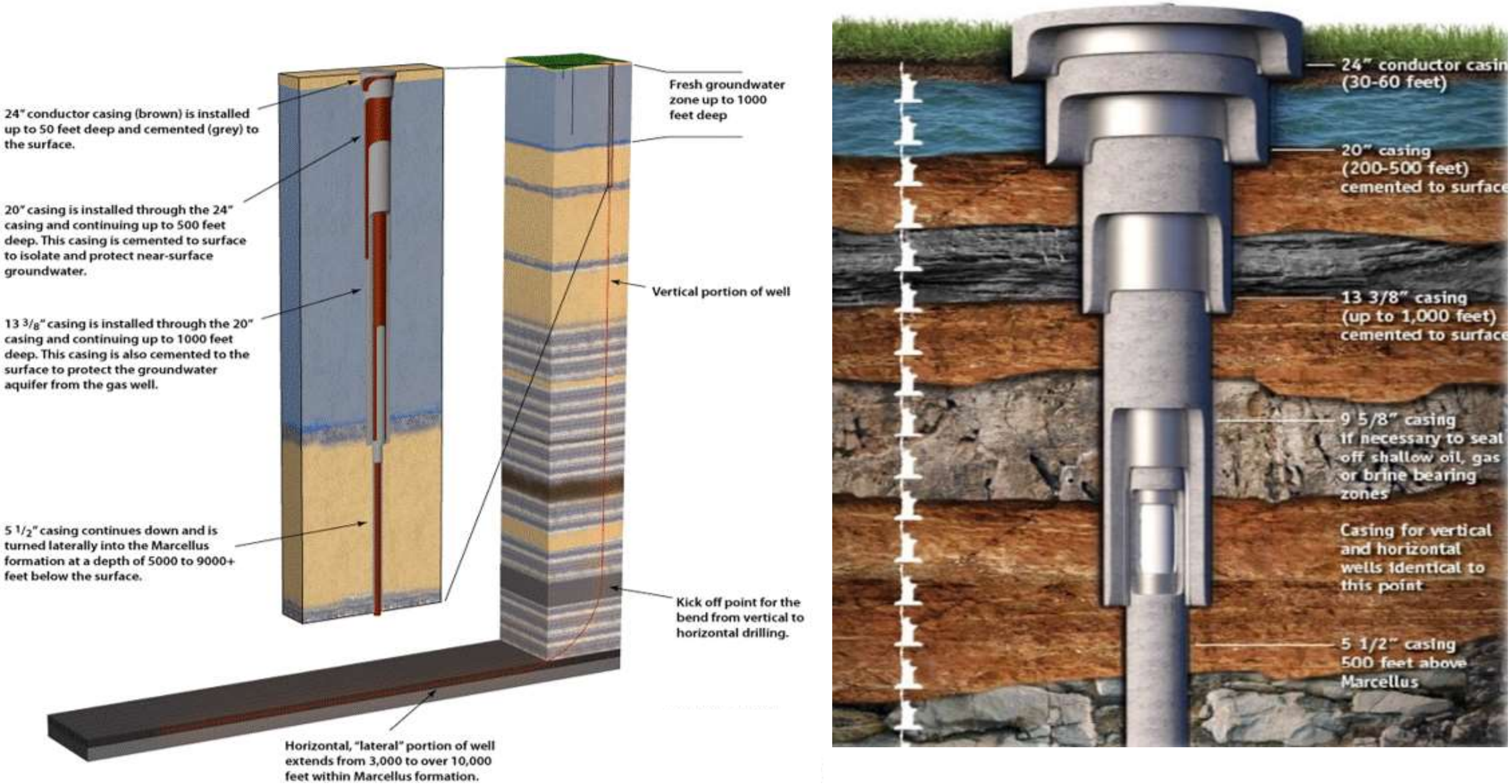


Figure SPM 1.7: Schematic demonstrating the vertical and horizontal drilling processes, typical of those in the Marcellus shale formation of Pennsylvania. The vertical section of the wellbore between the target shale formation and the surface is sealed with a steel casing and cement layers. In the upper sections of the wellbore, where it might pass through freshwater aquifers, multiple casing and cement layers are used. The near-horizontal section of the wellbore, which is 'fracked', runs along the shale gas-containing layer for up to several kilometres. It is lined with steel casing perforated with holes created by explosive charges. Source: Tom Murphy (n.d.), Pennsylvania State University, USA.

The fracking fluid consists of water and several additives, some of which are toxic or hazardous. The several tens of millions of litres of fluid are stored temporarily in tanks on the surface at each wellpad. Once used, the 'flowback' fluid that returns to surface consists of a mixture of the some of the original fracking fluid compounds, with a higher percentage of water and fine solids originating from the targeted shales. As much as possible of the flowback is re-used in later operations. The remnant water after fracking has ceased, is cleaned to a quality specified in legislation, with residual contaminants disposed of in a licensed site in an appropriate manner (SPM Box 1, Figure SPM 1.7). [§1.4.3.2.2.1]

SPM Box 1: The composition of fracking fluid

Over a thousand specific compounds are known to have been added to fracking fluids worldwide. The broad types and their relative quantities and properties are given below. A number of chemicals are currently prohibited from use in South Africa in any fracking activities.

Component	*%*	*Comments*
Water	95	Does not have to be freshwater, saline water can be used
Sand or ceramic proppant beads	4	Props open the cracks. Very fine, so silica in it can be a health hazard to wellpad workers if inhaled
Hydrochloric acid	1	Dangerous in concentrated form, for example, while being transported
Polyacrylamide		Non-hazardous, however breakdown products may be toxic & carcinogenic
Glutaraldehyde		Biocide (poison) used to eliminate corrosion-causing bacteria in water. Toxic and a strong irritant to humans
Polyethylene glycol		Toxic at high concentrations

Some of the fracking fluid injected into the well returns to the surface via the wellbore when the pressure is released. This is called "flowback" may contain compounds present naturally in the geological formation which is fracked. Some of the additional constituents in flowback, such as brine, heavy metals or radioactivity, may also be potentially hazardous. The most hazardous constituents of the flowback are separated and treated in the wellfield, concentrated and dispatched to an off-site disposal site. The remaining fluid can be re-used for further fracking operations. [§1.4.3.2.2.1]

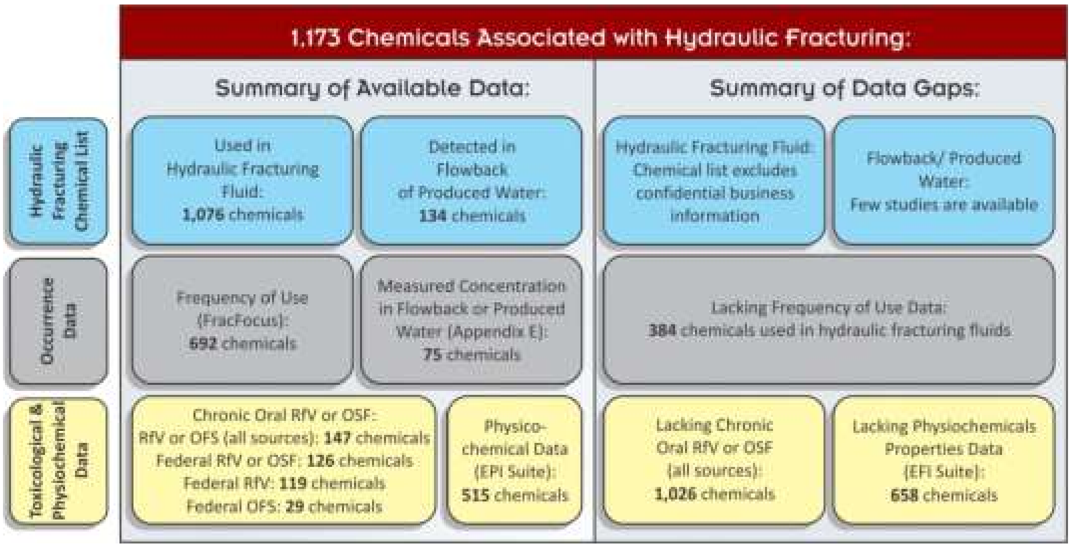


Figure SPM 1.8: Summary of information regarding chemicals used in fracking, highlighting gaps in knowledge.
RfV refers to Reference Value, an estimate of the exposure that is likely to be without an appreciable risk of adverse effects to humans over their lifetime. OSF is the oral cancer slope factor, a measure of carcinogenicity (Environmental Protection Agency, 2015). [§1.4.3.2.2.1]

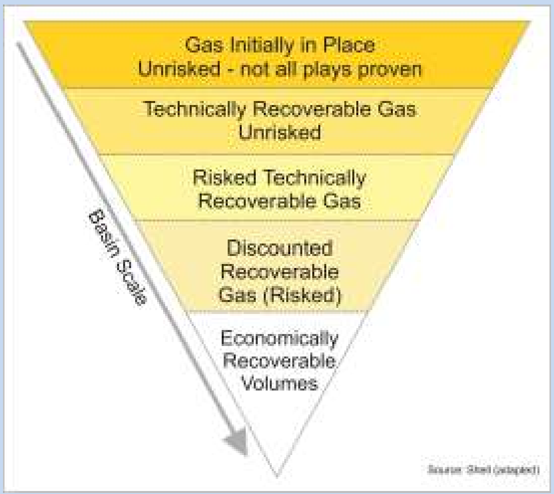
1.3 Shale gas development scenarios and activities

There is no history of production of shale gas in South Africa, so this description of potential scenarios and related activities is necessarily hypothetical. A summary of the main activities of SGD, for three scenarios, is provided in Table SPM 1.1. For detailed information, see Chapter 1 (Burns et al. 2016).

For the assessment, the *Reference Case* assumes shale gas exploration does not proceed. For this scenario (and the other scenarios included in the assessment), regional trends such as human migration, shifting economic activities and new development alternatives in the Central Karoo are assumed to continue. Climate change is assumed to have marked effects on ecosystems and the services they provide to communities. [§1.2.3]

In the *Exploration Only* scenario, exploration is assumed to take place, but not production. Exploration results reveal that production would not be economically viable. All sites are rehabilitated, drilled wells are plugged and monitoring of the abandoned wells is implemented. National energy needs, based on gas, are supported by imported gas product. [§1.4.3]

SPM Box 2: Economically recoverable gas volumes at the basin scale



Technically recoverable resources represent the volumes of natural gas that could be produced with current technology, regardless of petroleum prices and production costs. A large number of direct sub-surface measurements (depth, mineralogy, total organic content, thermal maturity, etc.) gathered by current drilling technology need to be undertaken to quantitatively calculate a technically recoverable gas reserve. Economically recoverable resources are those that can be profitably produced under current market conditions. The economic recoverability of gas resources depends on three factors: the costs of drilling and completing wells, the amount of gas produced from an average well over its lifetime, and the prices received for the produced gas. [§1.3.2]

Under the *Small Gas* scenario about 5 trillion cubic feet (Tcf) of gas are extracted. For comparison, the Mossel Bay offshore gas field will yield a total of about 1 Tcf. Downstream development in the Small Gas scenario results in a 1 000 MW combined cycle gas turbine (CCGT) power station located within 100 km of the production block. [§1.4.4]

The *Big Gas* scenario assumes a relatively large shale gas resource of 20 Tcf is developed. For comparison the offshore conventional gas fields in Mozambique contain about 100 Tcf. Downstream development results in construction of two CCGT power stations, each of 2 000 MW generating capacity, and a gas-to-liquid (GTL) plant, located at the coast, with a refining capacity of 65 000 barrels (bbl) of liquid fuel per day. [§1.4.5]

Certainty about what technically and economically extractable gas reserves may occur within the study area requires detailed exploration, including test fracking of the Karoo Basin shales. It is possible that no economically recoverable gas reserves exist at all in the study area. At the other extreme, the economically recoverable reserves may be greater than the Big Gas scenario considered here – in which case, associated impacts of SGD will be quantitatively larger, but not qualitatively different. Typically, only a small fraction of the total amount of gas present in a shale formation can actually be extracted at an affordable cost (SPM Box 2). The economic viability of SGD in the Central Karoo will depend on the gas price and production costs at the time when the gas is produced, which will be many years from now, if at all. In the interim, the extraction technology may advance, lowering the costs associated with production in the future. [§1.3.2]

Table SPM 1.1: Summary of the activities described in the three shale gas development scenarios.

Unit	Exploration Only	Small Gas	Big Gas
Trillion cubic feet (Tcf)	-	5	20
Production block/s [30 x 30 km well field]	-	1	4
Combined cycle gas turbine [1 000 MW]	-	1	-
Combined cycle gas turbine [2 000 MW]	-	-	2
Gas-to-liquid plant [65 000 bbl]	-	-	1
Number of wellpads [2 ha each]	30	55	410
New roads (km) [unpaved, 5 m wide]	30	58	235
Total area of wellpads and new roads (ha)	75	199	998
Percentage spatial coverage of study area	< 0.0001	0.0002	0.0009
Total number of truck visits	45 000	365 000	2 177 000
Industry water needs (m^3) [assuming no re-use of fluids]	*488 250	**9 212 625	***65 524 500
Industry water needs (m^3) [assuming re-use of 50% drill fluid + 30% frack fluid]	*319 110	**6 056 160	***43 087 235
Flowback waste (m^3) [sludge + brine + water]	*101 400	**5 573 900	***40 356 400
Other hazardous waste (t) e.g. oil, grease	*85	**635	***4 185

* For five exploration drilling campaigns, each with six exploration wells = total 30 wells over lifetime of Exploration Only
** For 55 wellpads, each with 10 wells, total 550 wells over lifetime of a Small Gas
*** For 410 wellpads, each with 10 wells, total 4 100 wells over lifetime of a Big Gas
Note: gas production pipelines assumed to be located within the road reserves
Note: data extracted from Burns et al. 2016 [§1.4, §1.5 and §1.6]

2. EFFECTS ON ENERGY PLANNING AND ENERGY SECURITY

The South African energy system is currently based mainly on coal mined in South Africa, complemented by imported oil and petroleum fuels with small quantities of natural gas. Smaller contributions from biomass, natural gas, nuclear and imported hydro-power make up the remainder of South Africa's primary energy supply. In recent years the contribution by 'renewables' (energy sourced from the sun and wind) has increased. Currently, natural gas is used only in small quantities. Most energy in South Africa is supplied as electrical power, about 90% of which is generated by burning coal. The portion supplied as heat is small. The transport sector uses liquid fuels, which are either imported (in both crude and refined form) or domestically produced using coal-to-liquid (CTL) and to a lesser extent GTL processes. [§2.1.2]

Energy planning in South Africa is performed at the national level, through several interrelated processes. The National Development Plan (NDP 2030) is the overarching planning document for the development of South Africa, and aims to reduce unemployment, eliminate poverty and reduce inequality by 2030. It has clear objectives and actions aimed at increasing natural gas use in the energy mix, irrespective of whether that gas is imported or sourced domestically. Actions proposed in the NDP 2030 include investigating shale gas opportunities and exploiting them in a sustainable manner should they be economically viable. The Integrated Energy Plan (IEP) takes its lead from the NDP 2030 and links the plans for the various energy sectors via a strategic energy planning framework into a plan for the entire South African energy system. The Integrated Resource Plan (IRP) is the electricity plan for the country. The draft Gas Utilisation Master Plan (GUMP) provides a long term roadmap for the strategic development of natural gas supply and demand. All these plans are led by the Department of Energy (DoE), in consultation with other government entities and non-governmental stakeholders. [§2.1.3]

Including more natural gas in South Africa's energy mix would make the energy system more resilient, efficient, cheaper and reliable. Natural gas, regardless of its source, has a desirable set of qualities that coal and oil do not possess. Natural gas can be used in almost all subsectors (power generation, heat, transport, chemicals manufacturing); is easily transported once a gas infrastructure is in place; is supported by a growing international market; is a more homogenous fuel than coal (thus more flexible and easier to handle); produces less carbon dioxide (CO_2) per unit of useful energy when burnt than coal (and is thus less climate damaging, provided leakage during production and transport is minimised); can be more efficiently used for power generation (more kWh per GJ); has high operational flexibility; and has an end-use cost structure that is relatively capital- light and fuel-intensive, making it more economically flexible than many alternative energy sources. [§2.1.2]

Table SPM 2.1: Summary of annual shale gas production over a 40 year period per scenario with associated estimated costs.

Based on accepted industry practice and notational energy planning resources. [§2.2.2]

Scenario	**Available shale gas**	**Annual shale gas production (40 years)[1]**	**Estimated cost of shale gas[1]**
Exploration Only	0 tcf	0 PJ/a	n/a
Small Gas	5 tcf ≈ 5 300 PJ ≈ 1 500 TWh	130 PJ/a ≈ 40 TWh/a *(≈50% of current natural gas supply in South Africa)*	6-10 US$/MMBtu = 20-35 US$/MWh
Big Gas[2]	20 tcf ≈ 21 000 PJ ≈ 5 900 TWh	530 PJ/a = 150 TWh/a *(2.5-3.0 times current natural gas supply in South Africa)*	4 US$/MMBtu = 15 US$/MWh

[1] *Estimated based on generally accepted industry practice and national energy planning resources.*
[2] *The "Big Gas" scenario of this book and the "Big Gas" scenarios of the IRP and GUMP are not the same scenarios and should be treated accordingly.*
Tcf = Trillion cubic feet; PJ = Peta-Joule; TWh =terawatt hours; MMBtu = equal to 1 million BTU (British Thermal Unit) ; MWh = megawatt hour

Gas is versatile in the national energy mix as it has a range of direct and indirect end-uses. In addition to generating electrical power, natural gas could be used for transportation, as feedstock to produce liquid transportation fuels, for fertiliser production, for industrial heat processes, for space heating and for residential cooking and water heating, if appropriately priced and secure in supply. [§2.2.2]

South Africa's three gas supply options are (1) pipeline gas imported from neighbouring countries, (2) Liquefied Natural Gas (LNG) imported by sea-going tankers and (3) produced in South Africa. South African sources include the possibility of offshore conventional gas fields within Exclusive Economic Zone on the West, South or East Coasts, or unconventional onshore sources such as shale gas or coal bed methane (CBM). South Africa will likely initially promote LNG imports to stimulate an anchor demand, supply initial power generation requirements, and establish a gas market. This would trigger investments into gas infrastructure and related investments into domestic conventional and/or unconventional gas exploration (including shale gas and CBM). These sources could be supplemented with increasing volumes of gas imported by pipelines. [§2.1]

Figure SPM 2.1: Power plant with three combined cycle gas turbines (CCGT) located in Algeria. Similar plants are planned as part of new CCGT capacity under the IRP 2010, regardless of whether exploitable shale gas is found in South Africa or not (Mubadala Development Company PJSC, 2016).

The availability of high volumes of shale gas at a competitive price could alter South African energy plans and further improve energy security. A likely outcome would be less use of coal. If the volumes of shale gas are high it is likely that the price will be relatively low. This will make gas-based power generation cost-competitive and cleaner than newly-constructed coal-based power stations, fundamentally altering planning assumptions and thus planning outcomes, especially in the IRP. [§2.2.2]

Use of shale gas enables the integration of more renewables into the mix and reduces the portfolio costs of power generation. Use of relatively low-cost shale gas would enable the creation of a network of gas-fired power stations under both the Small and Big Gas scenarios. These power stations have attributes complementary to solar photovoltaic and wind generation plants, which are inherently variable. Thus a portfolio containing all three is cheaper to build and operate than any one alone, for now and into the foreseeable future. Shale gas would not change the selected planning roadmap for the electricity sector, which already calls for more natural gas and renewables, but would likely make this path cheaper and cleaner. [§2.2.2]

Big Gas volumes extracted from shale in South Africa (or more) would make energy planning more integrated and resilient. Since the introduction of large quantities of relatively cheap natural gas creates links between previously de-coupled sectors, it would make energy planning slightly more complicated but at the same time would make it more integrated and resilient. Natural gas could act as the ‘pressure valve’ between sectors, allowing for adjustments between sectors if the planning assumptions are changed. [§2.2.2]

The risk to South African energy planning and security of not finding shale gas is very low. The IRP considers gas on the basis of its cost, not primarily on the basis of where it originates from. Gas demand could be supplied from imports if local sources are not viable. The risk relates to decisions on gas infrastructure investment, taken in anticipation of shale gas finds which subsequently do not materialise. This could result in energy infrastructure (including network infrastructure) that is not optimal for the energy future that occurs. This risk is low, as most of the planning decisions involving gas are ‘no-regret’ options with little risk of ‘lock-in’, and are based on rigorous infrastructure planning. The capital expenditure needed (for gas-fired power stations, gas-fired boilers, gas cooking, etc.) are small relative to alternative new-build options and therefore do not have a major effect on the overall costs of the energy system. [§2.2.2, §2.3.1]

Gas can assist historically disadvantaged populations to access modern energy sources. When complemented with energy access provided by a gas infrastructure, communities in the immediate area of SGD could benefit from the availability of natural gas and electricity as energy sources. Communities in the rest of South Africa would benefit indirectly via the broader macro-economic benefits anticipated from a local gas industry, reduced energy system costs and an environmentally cleaner power system. [§2.3.1]

3. AIR QUALITY AND GREENHOUSE GAS EMISSIONS

Without mitigation, the risk to shale gas workers of exposure to air pollutants is high, as is the risk to the climate from unintended methane leaks. With mitigation these risks can both be reduced to moderate. Many other risks related to air quality and GHGs are assessed as low or moderate without mitigation. Impacts depend on whether shale gas displaces a more or less emissions-intensive fuel. If actual methane leakage rates turn out to be at the high end of what has been seen elsewhere, they would negate the climate benefits of gas relative to coal as a low GHG-producing energy source. [§3.3.4]

There is insufficient information on air quality emissions and concentrations and GHG emissions in the Karoo to form a reliable baseline against which to measure the future impacts of SGD. There is no air quality monitoring stations within the study area. [§3.2.2.4]

Good practice guidelines are needed to minimise impacts on air quality and reduce GHG emissions in the event of SGD. The guidelines need to cover control technologies, effective legal regulation, early establishment of baselines, continuous monitoring and good governance enabled by coordination across several institutions. [§3.4]

3.1 Air Quality

SGD without mitigation would be associated with a high risk of occupational exposure to air pollutants. SGD activities that result in health risks at the wellpad are the emissions of diesel exhaust, nitrogen dioxide (NO_2), particulate matter (PM), volatile organic compounds (VOCs), silica and hydrogen sulphide (if present in the shale gas). Occupational exposure risk can be mitigated to moderate by decreasing respirable crystalline silica emissions using best practice. It is more difficult to mitigate risks from diesel exhaust and VOCs. [§3.2.4.2]

Under scenarios of Small and Big Gas development, in the absence of mitigation, there is a moderate risk of local community exposure to air pollutants. For communities within the study area, the risk of exposure to air pollution is driven by the increase in ambient PM concentrations, which already exceeds the National Ambient Air Quality Standards (NAAQS) at the one monitoring station closest to the study area, due to mineral dust of non-mining origin. SGD activities would dominate regional emissions of air pollutants other than dust, due to the currently low level of industrial activity in the study area. Even with these relatively large emission increases, ambient concentrations of pollutants other than PM should remain within NAAQS. With mitigation involving available technologies and best practice, the risk of local community exposure to NO_x, PM and VOCs can be reduced to low. [§3.2.4.3]

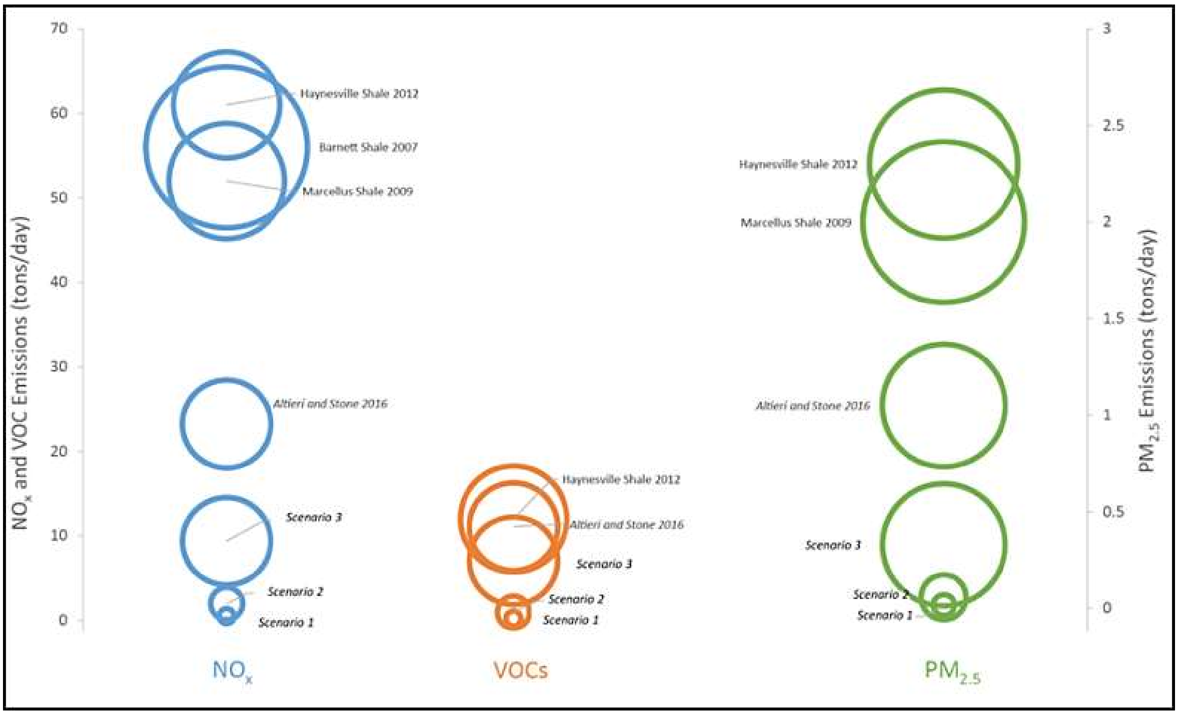


Figure SPM 3.1: Estimated air pollutant emissions resulting from shale gas development in the Central Karoo.

The data are from this assessment, Altieri and Stone (2016) and main shale plays in USA (Marcellus from Roy et al., 2014, Barnett from Armendariz, 2009 and Haynesville from Grant et al., 2009). The “bottom-up” South African estimates are much lower than the actual USA observations for three reasons: 1) the number of wells in the USA is larger than anticipated for South Africa (indicated by the size of the circles); 2) some states in the USA have weak regulatory regimes; and 3) the newer technology which would be applied in South Africa is anticipated to be less polluting. Scenario 1 = Exploration Only; Scenario 2 = Small Gas; Scenario 3 = Big Gas.

The extensive use of heavy diesel trucks during SGD exposes the entire study area to increased levels of air pollution. The risk is assessed as moderate for both Small and Big Gas development due to truck traffic associated with moving equipment to and from well sites, transport of water to the well sites, and the transport of waste and water from the well sites to regional waste centres. Routing trucks away from places where people live and treating road surfaces to minimise dust can reduce the risk to low. [§3.2.4.4]

It is plausible that SGD could improve indoor air pollution in both the study area and the country as a whole. This benefit depends on shale gas or electricity derived from it displacing “dirty” fuels such as wood, coal, and paraffin for domestic use, especially when those fuels are burned indoors without adequate ventilation. [§3.2.4.1]

3.2 Greenhouse gas emissions

Shale gas presents both a risk of increased national greenhouse gas emissions and an opportunity to reduce emissions. The opportunity for emission reductions depends crucially on whether gas displaces coal (the main fuel in South Africa) or low-carbon energy sources, and to the degree to which gas is used *in addition* to coal. Shale gas used in place of coal for electricity generation will reduce CO_2 emissions, but the scale of reductions is slight in relation to the magnitude of national GHG emissions now and as projected over the period of SGD. The worst shale gas use option is comparable in emissions-intensity to the best coal use option (Figure SPM 3.2). [§3.3.4.3]

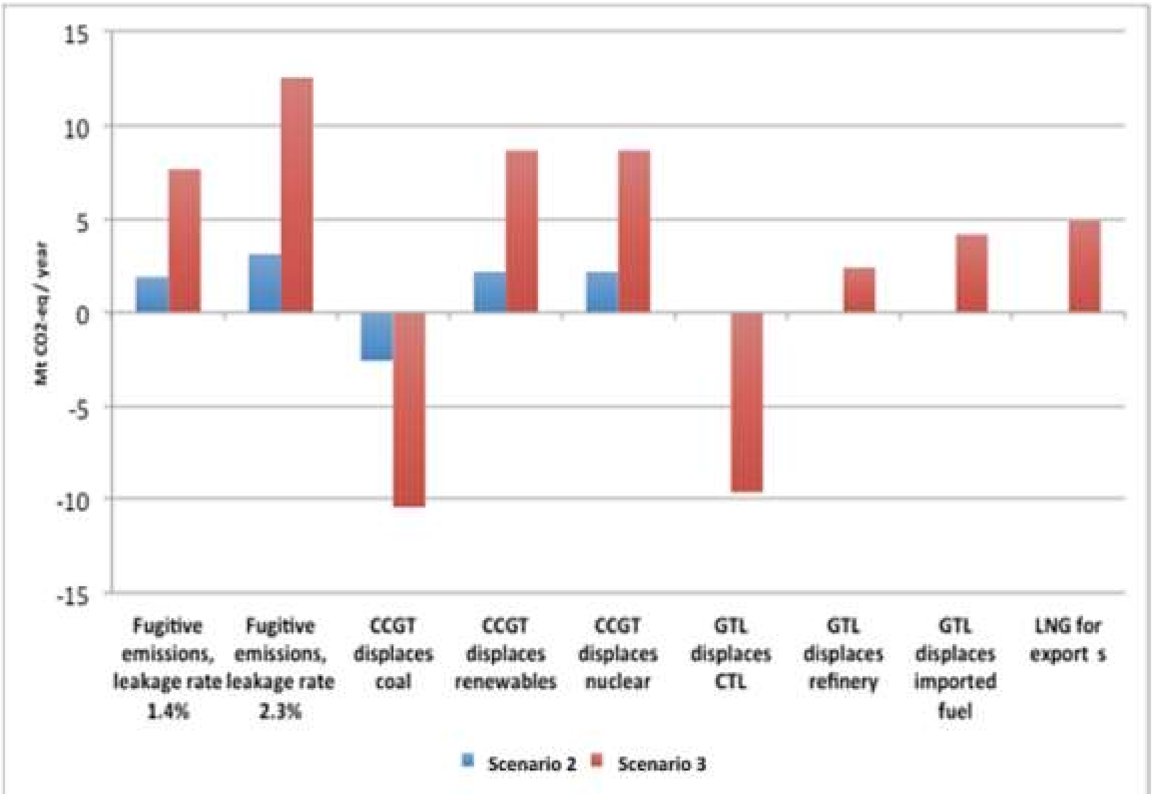


Figure SPM 3.2: Net change in national greenhouse gas emissions which would result from shale gas development under various assumptions.
The total South African emissions in 2010 were in the region of 400 Mt CO_{2eq}. Note that the outcome of SGD implementation could be either a small increase or a small decrease in national GHG emissions, depending on what is displaces and what fraction of the methane unintentionally leaks to the atmosphere in un-combusted form ('fugitive emissions'). Scenario 2 = Small Gas; Scenario 3 = Big Gas.

For the Big Gas scenario with inadequate control of gas leaks, the risk that fugitive methane emissions will result in the GHG benefits being greatly reduced or even reversed is assessed as high. Methane has a greenhouse warming potential twenty to thirty times higher than CO2, so leaks amounting to a few percent can offset the benefit that accrues from the higher energy yield per unit

CO_2 emitted when gas is used in the place of coal. The GHG no-benefit threshold occurs at 1.9% leakage under the Small Gas scenario, and 3.2% under the Big Gas scenario. The estimates of leakage worldwide are in the range 1.5 to 2.3%, but recent literature showing that much of the emission comes from a few "super emitter" locations suggests that the true range may be 2.2 to 4.1%. This risk could be reduced to moderate with mitigation involving good practice and available control technologies [§3.3.4.1]

4. EARTHQUAKES

The natural occurrence of a damaging earthquake (M>5) anywhere in the study area is considered to be very unlikely. The level of risk depends on the exposure of persons and vulnerable structures to the hazard. In the rural parts of the study area the exposure is very low, the consequences of an earthquake are likely to be slight, and hence the risk posed by earthquakes is considered to be low. While it is considered to be very unlikely that a damaging earthquake will occur within 20 km of a town, the consequences of such an event could be moderate or even substantial. Lives could be lost, and many buildings would need to be repaired. Hence the risk in urban areas is considered to be moderate. Exploration activities associated with the Exploration Only scenario do not involve the large scale injection of pressurised fluids, the risk posed by earthquakes in the study area during the exploration and appraisal phase is considered to be low and not significantly different to the baseline.

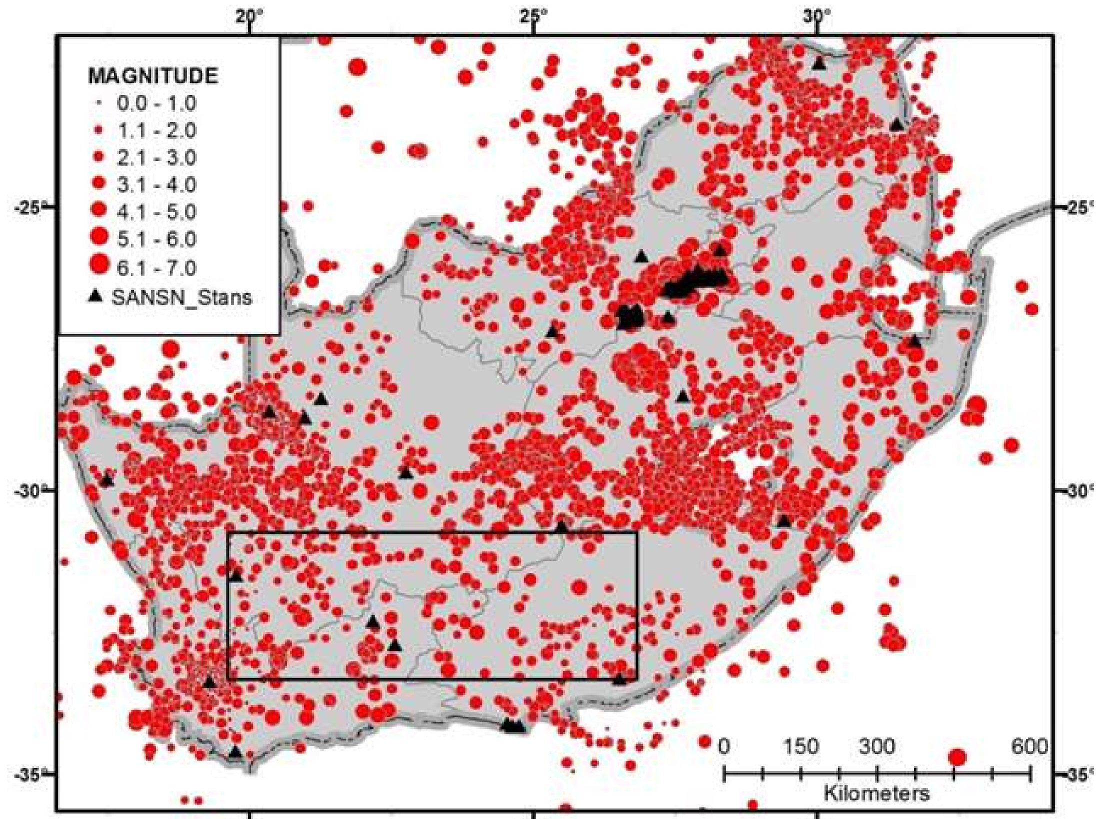


Figure SPM 4.1: Locations of recorded seismic events in South Africa between January 1811 and December 2014.

The black triangles are locations of seismic monitoring stations; the black rectangle is the study area. The study area is seismically quiet relative to other parts of South Africa and the world.

SGD by fracking increases the likelihood of small earth tremors near the well bores. Only a few such tremors are likely to be strong enough to be felt by people on the surface. Many studies, in several parts of the world, demonstrate an increase in small earth tremors during fracking. The possibility that fracking will lead to damaging earthquakes through triggering movement on pre-existing faults cannot be excluded, but the risk is assessed as low because the study area very rarely experiences tremors and quakes (Figure SPM 4.1). Damaging earthquakes associated elsewhere with SGD are almost exclusively linked to the disposal of large volumes of waste water into geological formations (a practice forbidden by South African legislation); rather than the development of shale gas resources using fracking. [§4.1.1, §4.1.3]

The risk to persons and assets close to fracking operations in rural areas, such as workers, farm buildings and renewable energy and Square Kilometre Array (SKA) radio telescope infrastructure, should be handled on a case-by-case basis. Vulnerable structures, including features of heritage importance, should be reinforced and arrangements made to insure or compensate for damage. Should particularly attractive shale gas resources be found close to towns, it is essential to inform local authorities and inhabitants of any planned fracking activities and the attendant risks; enter into agreements to repair or compensate for any damage; monitor the induced seismicity; and slow or stop fracking if felt earthquakes are triggered. [§4.4]

The authors cannot categorically exclude the possibility that an earthquake may be triggered by fracking. The Earth's crust is heterogeneous and physical processes are complex. Rock properties and geodynamic stresses are not perfectly known, and the seismic history is incomplete. It is thus important that seismicity is monitored for several years prior to any fracking, and that a seismic hazard assessment is performed to provide a quantitative estimate of the expected ground motion. Monitoring should continue during SGD to investigate any causal link between SGD and earthquakes. Should any such link be established, procedures governing fluid injection practice must be re-evaluated. [§4.3.2]

It is recommend that Council for Geoscience's seismic monitoring network be densified in the study area, and that vulnerability and damage surveys of buildings and other structures be carried out before, during and following any SGD activities. At the present time (August 2016) an additional six seismograph stations were being installed by the Council. Other mitigation measures to be considered should include: monitoring of seismicity during SGD and the slowing or stopping of fracking if felt earthquakes are induced, schemes to guarantee compensation in the case of damage, disaster insurance, reinforcement of vulnerable buildings (especially farm and heritage buildings, schools and hospitals), enforcement of building regulations, training and equipping of emergency first responders, and earthquake drills in schools and work places. [§4.2.4]

5. SURFACE AND UNDERGROUND WATER RESOURCES

Each well requires in the region of 10 500 m^3 of water to be fractured. The exact amount of water required depends on hole depth, geological conditions and the number of fracturing stages required. Assuming water re-use at 50% of drill fluid and 30% of fracking fluid, in the region of 6 000 000 – 45 000 000 m^3 would be required for the Small Gas and Big Gas scenarios respectively. The quality of the water does not have to be of a potable standard and can be salty or 'brackish'. [§1.4.3.2.2, §1.4.4.2, §1.4.5.2, §5.2.2.2]

There is not capacity to supply water for SGD from existing local sources. Water availability in the study area is severely constrained. Surface water availability is generally low, and in many areas over-allocated. Landowners rely mainly on groundwater resources for domestic and stock water. Groundwater recharge is typically low and sporadic. The use of groundwater is increasing, particularly during drought years. In many areas, groundwater already supplies 100% of the use. The availability of groundwater to meet the demand of even the Reference Case (where there is no SGD), is already seriously constrained. The additional demand under the Small and Big Gas scenarios could not be met from known local potable resources and would be considered a very high risk if local resources were utilised. [§5.2.2, §5.2.3, §5.2.4, §5.3]

There is potential to develop non-potable (brackish) groundwater within or near the study area, at a limited scale. This would need to take into account the potential risks associated with the transport and storage of brackish water, as well as potential risks associated with large water wellfield developments in the Central Karoo. [§ 5.2.2.2]

Surface spills on-site and along transport networks are the most likely source of water resource contamination. The risks of fracking fluids reaching near-surface waters by percolating upward from the fracking zone are considered very low. Risks of leakage from faulty wellbore linings in the top few hundred meters are higher, but manageable (moderate risk) if best practice techniques are utilised. The likelihood of spillages on the wellpad or during transport is near inevitable under both production scenarios. Spills, on average, are expected to have localised and short-term consequences (Figure SPM 5.1). [§5.5.1]

The most effective management action is to avoid high sensitivity water resources. These have been mapped, at a high-level, in as hypothetical 'set-backs' (see Figure SPM 5.2). The sensitive areas are deliberately conservative, considering the low confidence in scale and available data. Additional investigations will be required at an Environmental Impact Assessment (EIA) level to determine 'no-go' areas. It can be stated with reasonably high confidence that SGD activities located in areas of medium sensitivity will reduce the risk profile to low and very low for all direct water impacts. [§5.7.3]

Post-SGD legacy impacts will occur. There will be impacts following the completion of SGD from failed well linings or capping structures on spent production wells. It is highly unlikely that all decommissioned production wells will maintain their integrity indefinitely. The associated risk is constrained by the likely number of failures and localised zone of influence, and is therefore assessed as low in the Small Gas scenario and moderate in the Big Gas scenario with and without mitigation. Where monitoring data allows the impact to be traced, containment is feasible following site-specific assessments to identify appropriate mitigation. Contamination may only arise long after SGD has ceased. Systems for contamination detection and funding for remediation must be in place. [§5.5.1.4]

Water resources monitoring before, during and after SGD is an imperative. A comprehensive set of baseline water resource data for the study area must precede SGD. This must include establishment of water availability and verification of existing use, including the water resources needed to meet environmental requirements, the "Reserve". The baseline must also include quantification of the quality of surface water and groundwater. The authority responsible for issuing water use licences (Department of Water and Sanitation) will not do so before comprehensive reserve determinations for groundwater, surface water and wetlands are completed. Ongoing water resource quality monitoring including general and SGD-specific determinants is essential during and after SGD. [§5.4.3.1, §5.8]

The capacity to undertake the analyses necessary for water chemistry monitoring in relation to SGD is currently inadequate in South Africa. Most accredited South African water quality laboratories are equipped to carry out routine water analyses; however, none are presently capable of analysing for SGD-specific determinants such as $\delta^{11}B$, $^{36}Cl/Cl$, ^{4}H, $^{3}H/^{4}H$, and CH_4. Sufficient lead-in time must be allowed for such facilities to be set up prior to SGD. Near-term baseline establishment may require the use of accredited laboratories elsewhere in the world. [§5.8.2]

Lack of infrastructure and institutional capacity for water management is currently a constraint in the Central Karoo and are considered a high risk which can be reduced to moderate with mitigation. The present institutional and human resource capacity is insufficient to implement a robust and effective water resource monitoring and management programme for SGD. This constraint applies especially to regulatory authorities, who often lack the necessary skills and the will to enforce regulations, and less so to the SGD industry, which it is expected will mobilise the necessary resources to meet regulatory requirements in this regard. The likelihood of environmental non-compliance is increased by poorly capacitated regulators, largely reliant on information supplied by the industry. [§5.5.3.2]

SGD provides a learning opportunity that can improve understanding of local water resources. The activities associated with exploration for shale gas would generate new geoscientific data and information which will advance the understanding of the geology, hydrogeology, geophysics and geochemistry of the study area. The discovery of, as yet, unknown groundwater resources is a possibility. This opportunity would however be realised whether SGD advances to production capacity or not, as the potential will be revealed mainly during the exploration phase. [§ 5.7.1]

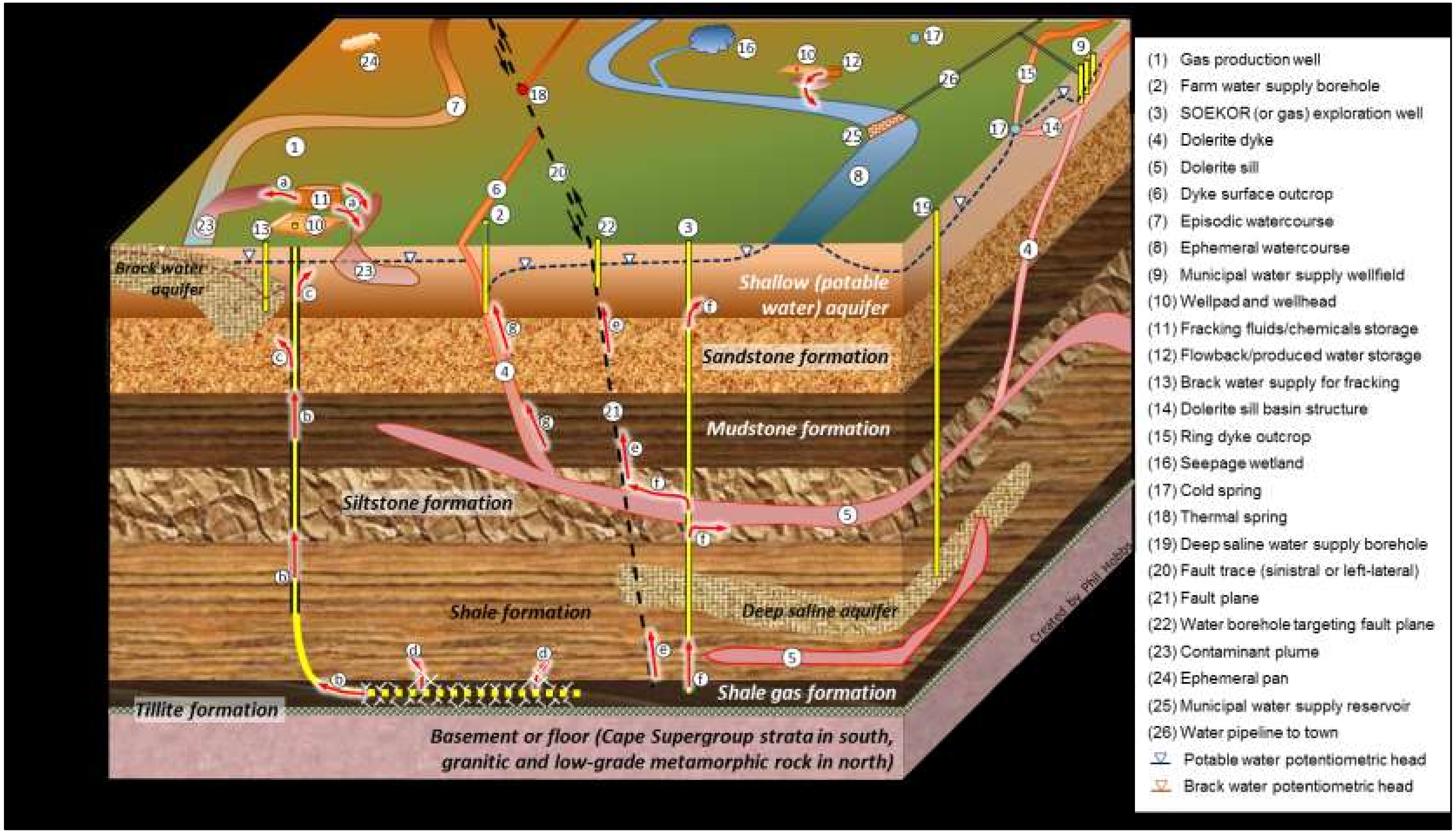


Figure SPM 5.1: Features associated with the surface water and groundwater environments in the Central Karoo as these relate to shale gas development activities. The possible contaminant pathways (red arrows) and plumes (feature 23) are conceptual and exaggerated for purposes of illustration. The thickness and types of rock layers is similarly illustrative only; in reality the various formations comprise a mixture of sedimentary rock types, and are not uniformly thick or necessarily horizontal. Features 3 and 19 might be artesian. The possible contaminant pathways are identified as (a) surface spills at the wellpad, (b) flowback and produced water via a production well, (c) leakage via faulty annular seals in production wells, (d) migration via hydraulic fractures, (e) preferential migration along fault planes, (f) leakage from old (possibly uncased) oil and gas exploration wells, and (g) preferential migration along dyke or sill contact zones.

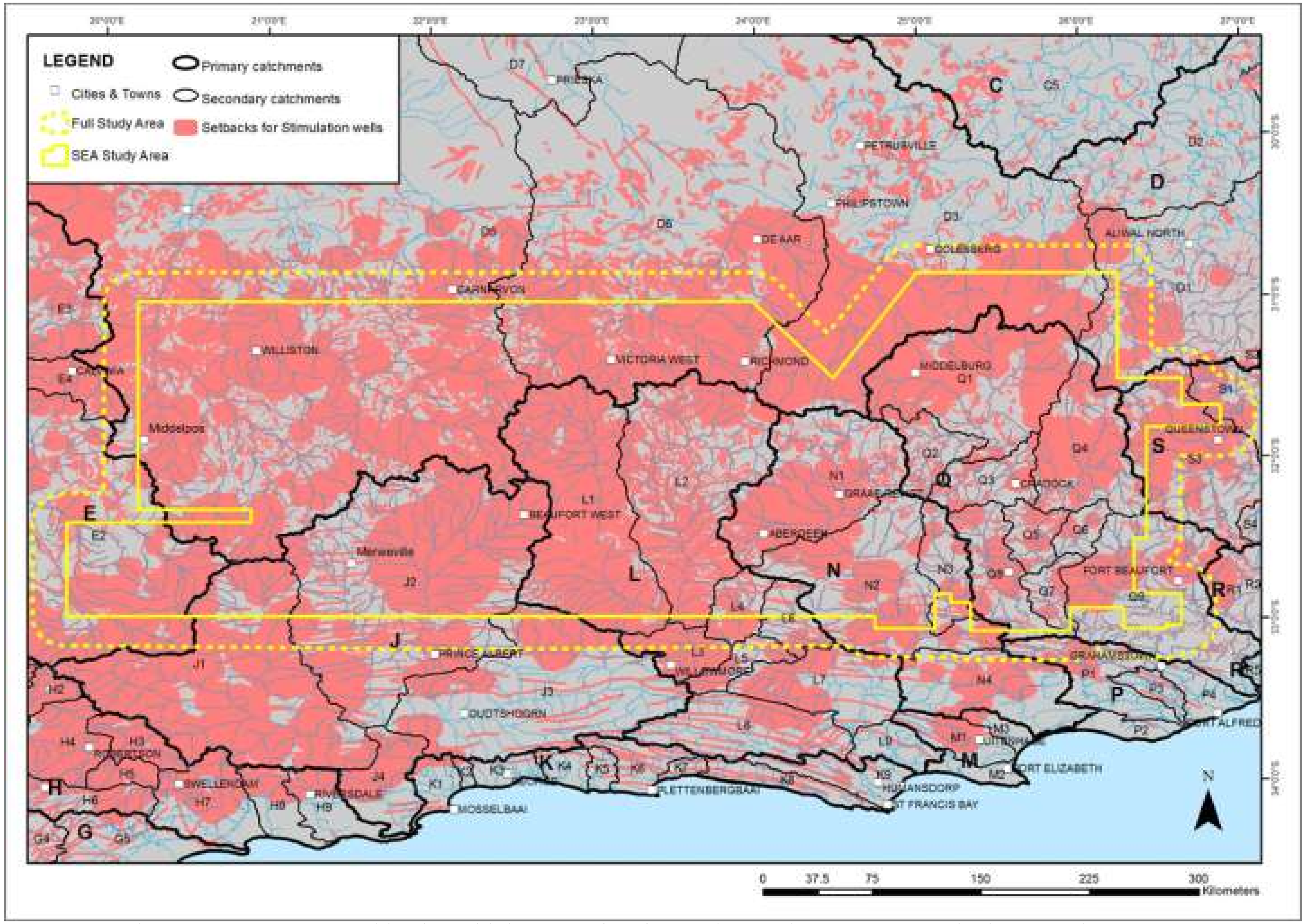


Figure SPM 5.2: Combined sensitivity map of surface and ground water resources in the Central Karoo.

The highlighted pink areas are of high sensitivity and are ‘hypothetical set-back’ areas. These comprise the areas in which impacts to water resources are possible, and if so, might have highly negative consequences (assessed with a medium-level of confidence). The grey areas are considered of medium sensitivity - in these areas, the risk to surface and groundwater resources can be significantly reduced to low and very low, assessed with a high-level of confidence. Additional investigations will be required at an EIA level to determine actual ‘set-back’ areas based on ‘ground-truthed’ site specific information.

6. WASTE PLANNING AND MANAGEMENT

SGD will generate substantial volumes and new types of waste. This includes liquid wastes such as flowback. Volumes of flowback will range from around 6 000 000 m^3 for the Small Gas scenario to around 40 000 000 m^3 for the Big Gas scenario (see Table SPM 1.1). Solid mining wastes such as bore fragments and cuttings, industrial wastes such as used machinery and supplies, as well as more conventional wastes such as sewage, domestic waste and construction waste will also be generated. [Table §1.4; §1.5 and §1.6 from Burns et al., 2016]

Under the Big and Small Gas scenarios the risks of exposure to waste streams is high. The risks of waste streams originating from exposure to hazardous and domestic waste streams; as well as the additional sewage load at already stressed waste water treatment works can be mitigated to low if waste from SGD is managed in line with the *waste management hierarchy* and the existing regulations and the principles for integrated waste management in South Africa. The emphasis is on minimising waste generation, promotion of the use of non-hazardous chemicals, re-use and recycling and minimisation of the impact of waste on water, the environment and communities. [§6.1]

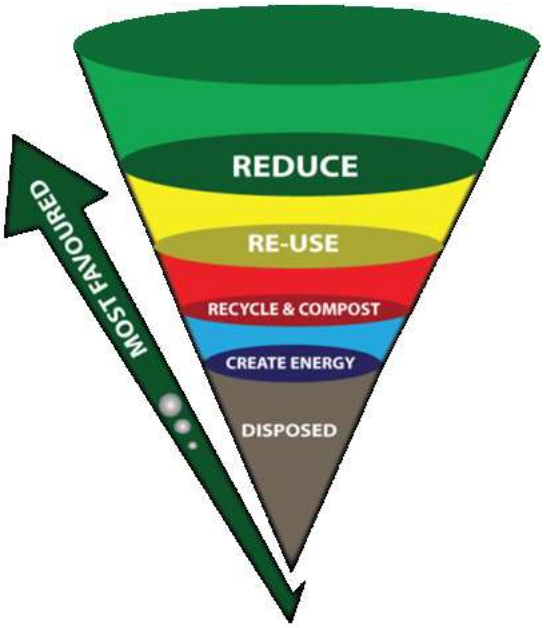


Figure SPM 6.1: Schematic of the Waste Management Hierarchy.
The hierarchy favours options for reducing waste wherever possible, re-using all types of waste related to SGD, recycling of materials such as flowback fluids and then disposal as a final step if none of the previous options prove feasible.

Waste should be treated on site by the SGD industry. Municipal waste disposal sites are at jeopardy of receiving waste from SGD if an imminent amendment to the Waste Act, 2008 results in SGD waste being classified as general waste. Municipal landfills in the study are not designed or equipped to receive SGD waste and municipal staff do not have the skills or experience to manage it responsibly. The SGD industry, and not local municipalities, should be responsible for the treatment of waste streams onsite and safe disposal thereof emanating from exploration and/or operations.

There are five basic management options for contaminated waste water from SGD. These are: 1) Minimisation of produced water generation; 2) Recycling and re-use within operations; 3) Treatment; 4) Disposal; and 5) Beneficial re-use outside the operations (see Figure SPM 6.2). [§6.1.2]

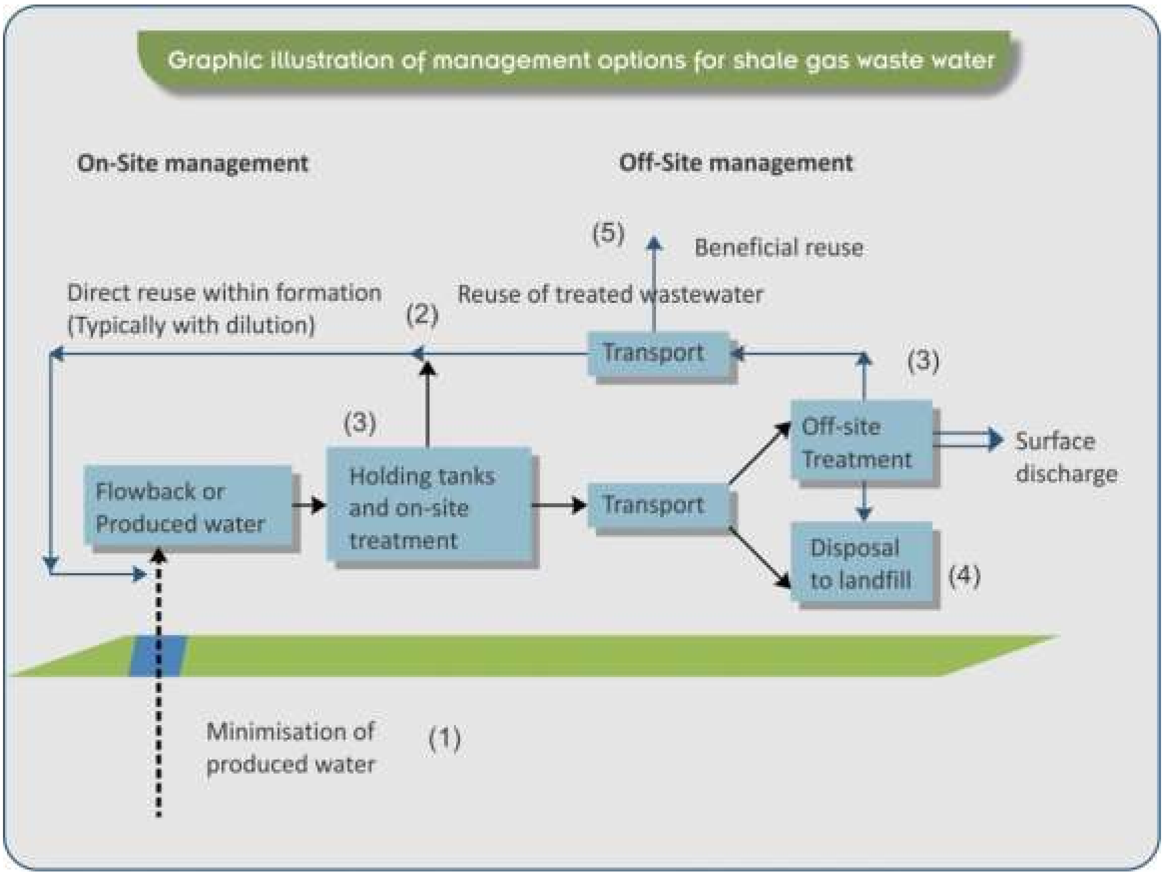


Figure SPM 6.2: Five management options for contaminated waste water from shale gas development.

The existing legislated waste management provisions in the Regulations for Petroleum Exploration and Production 2015 are largely adequate to reduce the waste-related risks of SGD to low, if rigorously enforced. This assessment has assumed that the Regulations for Petroleum Exploration and Production 2015 are mandatory and will not be relaxed by any future amendments. Recovery of drilling muds and fracking fluids will require a waste management license in terms of the Waste Act (2008). It is recommended that SGD wastes be added to the list of pre-classified hazardous waste streams in Annexure 1(2) of waste Regulation 634 (RSA, 2013). [§6.1.1, §6.3.1]

Norms and standards for waste classification and containment barrier system designs are prescribed, but the law is silent on landfill management, operational and groundwater monitoring requirements at facilities receiving waste from SGD. Development of norms and standards in terms of the Waste Act, 2008 specific for discharge of treated shale gas flowback and produced water may be required to ensure equal and adequate protection of all the water sources and associated ecosystems and communities in the study area. [§6.3.3, §6.4.5]

There is a current lack of staff, skills and expertise at all spheres of government to assess the increased volume of waste licence applications relating to SGD especially in the Big and Small Gas scenarios. The waste streams from SGD are new to South Africa and therefore capacity needs to be created to evaluate licence applications efficiently and responsibly. [§6.3.3]

There is insufficient laboratory capacity in South Africa able to perform the volume of analyses necessary for operational waste classification under the Big or Small Gas scenarios. The analyses must be undertaken at South African National Accreditation System (SANAS) accredited laboratories, very few of which have accreditation for the prescribed tests. Additional laboratory capacity will be needed to deal with the volume of analyses that would be required for SGD. [§6.3.3, §6.5.3.3]

Currently, no sites are licensed for Type 1, 2 or 3 hazardous waste disposal in the study area. This means that any *Type 1, 2 or 3* hazardous waste would need to be transported and disposed of outside the study area. Leach management and treatment is a pre-requisite for disposal of shale waste due to the presence of a range of toxic chemical additives, salinity and potentially radioactivity (leachable Naturally Occurring Radioactive Materials) in flowback water. These substances require particular handling for safe disposal. The institutional capacity, skills and knowledge to implement and enforce waste regulations, norms and standards is limited, especially at local level and will have to be strengthened before SGD is approved. [§6.2, §6.3.3, §6.4.3]

7. BIODIVERSITY AND ECOLOGICAL IMPACTS

The study area includes high levels of biodiversity by global standards, including sensitive and unique ecosystems and species. Seven different biomes and 58 vegetation types, 119 endemic or near-endemic plant species and 20 threatened animal species have been recorded from the study area. [§7.1.3]

The Karoo is characterised by ecological processes that operate over extensive areas. The aridity of the Karoo makes the ecosystems sensitive to disturbance. Recovery from disturbance is slow and generally not spontaneous. Active rehabilitation is often met with poor success. [§7.1.3]

A major concern is that the roads, pipelines and powerlines associated with SGD will result in fragmentation of the landscape. Loss of connectivity, edge effects and disruption of ecological processes associated with a network of linear structures are likely to undermine the biodiversity integrity of the study area. Impacts on species, ecosystems and ecological processes extend well beyond the physical footprint of the activity. For many species the impacts of noise, pollution, erosion and other disturbance can extend for hundreds of metres or kilometres from the source. Impacts on species and ecological processes are likely to have cascading effects on other species and processes. [§7.2.2, §7.2.3]

The assessment has identified areas of Ecological and Biodiversity Importance and Sensitivity (EBIS), from EBIS-1 (highest) to EBIS-4 (lowest). The primary mitigation for SGD with respect to biodiversity is avoiding and securing EBIS-1 and EBIS-2 areas. This effectively makes the EBIS-3 and EBIS-4 areas available for SGD. [§7.2.1, §7.3.1]

Strategic mitigation at the landscape level is essential, as the impacts of SGD cannot be effectively mitigated on site or at the operational level. EBIS-1 and EBIS-2 areas make up an estimated 50 % of the study area. Loss or degradation of habitat in these areas must be avoided and they should be secured through legal mechanisms. Securing these areas may lend itself to a fast-tracked, integrated protected area expansion strategy (Figure SPM 7.1,
Table SPM 7.1). [§7.3]

EBIS-1 areas contain extremely sensitive features and are irreplaceable. Impacts of SGD in these areas would undermine the ecological integrity of the study area (and more broadly, the Karoo). Activities related to SGD in EBIS-1 areas are must be avoided. It is not possible to minimise or offset impacts of SGD in these areas. [§7.3]

EBIS-2 areas contain highly sensitive features that are important for meeting biodiversity targets and/or maintaining ecological processes in the study areas. Where SGD activities in EBIS-2 areas are unavoidable, the impacts must be minimised and residual impacts must be offset by securing ecologically equivalent sites in EBIS-1 or EBIS-2 areas. In the case of such offsets, national and provincial offset guidelines should be applied to ensure no net loss (see

Table SPM 7.2). [§7.3]

Environmental compliance in EBIS-3 and EBIS-4 areas is still required. This includes specialist-led assessment of local sensitivities and identification of appropriate mitigation. This is necessary to ground-truth desktop assessments and minimise impacts. [§7.3.4]

The cumulative and unforeseen impacts of SGD on biodiversity, as well as effectiveness of mitigation, must be monitored. The outcomes of the monitoring programme need to dynamically inform ongoing strategic and regional level decisions on SGD. [§7.4.2]

Figure SPM 7.1: Map of Ecological and Biodiversity Importance and Sensitivity in the study area. Protected areas (5% of study area) are legally protected. EBIS-1 areas (13% of study area) contain extremely sensitive features and are irreplaceable. EBIS-2 areas (37% of study area) contain highly sensitive features and/or features that are important for achieving targets for representing biodiversity and/or maintaining ecological processes. Protected areas, EBIS-1 areas and EBIS-2 areas collectively meet targets for representation of biodiversity and maintenance of ecological processes in the study area. EBIS-3 areas (44% of the study area) are natural areas that do not contain currently known sensitive or important features. In EBIS-4 areas (1% of study area) there is no remaining natural habitat (Figure SPM 7.1).

Table SPM 7.1: Extent of areas of Ecological and Biodiversity Importance and Sensitivity within the study area (percentage).

Ecological and Biodiversity Importance and Sensitivity	Extent (%)
Protected areas	5
EBIS-1	13
EBIS-2	37
EBIS-3	44
EBIS-4	1
Total	**100**

Table SPM 7.2: Strategic application of the mitigation hierarchy at the landscape level.

Based on map of Ecological and Biodiversity Importance and Sensitivity.

Ecological and Biodiversity Importance and Sensitivity (EBIS)	Primary focus of mitigation, based on the mitigation hierarchy
Protected Areas	**AVOID.** These areas are legally protected in terms of the Protected Areas Act.
EBIS-1 (highest)	**AVOID** – it is not possible to minimise or offset impacts of SGD activities in these areas. If possible, **SECURE** through legal mechanisms that limit habitat loss and degradation. These are first-tier receiving areas for biodiversity offsets.
EBIS-2	**Best option: AVOID** **Otherwise: MINIMISE, AND OFFSET RESIDUAL IMPACTS** by securing sites in EBIS-1 or 2 areas. If possible, **SECURE** through legal mechanisms that limit habitat loss and degradation. These are second-tier receiving areas for biodiversity offsets.
EBIS-3	**MINIMISE** SGD activities need not be avoided in these areas **IF:** • EBIS-1 areas are secured, AND • EBIS-2 areas are either secured or any residual impacts on these areas are offset.
EBIS-4 (lowest)	**MINIMISE**, especially in order to ensure that there are no negative impacts on protected areas, EBIS-1 or EBIS-2 areas.

8. IMPACTS ON AGRICULTURE

Agriculture functions on different levels or scales, including both a social subsystem and ecological subsystem. Decision-making within agriculture needs to consider both these subsystems, the agro-ecosystems agriculture depends on, as well as the governance systems organising and regulating agriculture in the Central Karoo. [§8.2.1]

The total Gross Farm Income (GFI) of the region is just over R5 billion/yr. Of which 48% is from the Eastern Cape, 10% from the Northern Cape, and 41% from the Western Cape. The sale of animals accounts for 39% of GFI, animal products 19%, field crops 4%, and horticultural crops 38%. The agricultural sector in the study area provides a direct source of income for 38 000 people. Considering the average size of families in the study area of approximately 4.5 persons; this translates to supporting the livelihoods of around 133 000 people. [§8.5.3.1, §8.5.3.2]

The biggest risk of SGD to agricultural production relates to the competing use and potential contamination of water resources. In the dryer central and western parts of the study area, farming communities rely exclusively on boreholes for water for humans and livestock consumption. Elsewhere, both surface and groundwater are used for livestock and irrigation purposes. SGD poses potential risks to both the quantity and agricultural usability of surface and groundwater resources. Opportunities may exist to use water produced as a by-product of SGD for agricultural production purposes or importing water from outside of the Central Karoo, which will significantly decrease the risks associated with local water competition. [§8.6.2, §8.8.1, §8.8.2]

SGD and agriculture are not mutually exclusive. SGD does not pose a significant risk to agricultural productivity in the long term if the risk to ground water resources is adequately addressed. The central and western parts of the study area are areas of low potential productivity in a national context. Nevertheless, they have made a relatively constant contribution to regional Gross Domestic Product (GDP) and sustained local livelihoods. The area offers limited options and opportunities. There is a trend towards alternative sources of land-based incomes, such as eco-tourism and hunting. [§8.5]

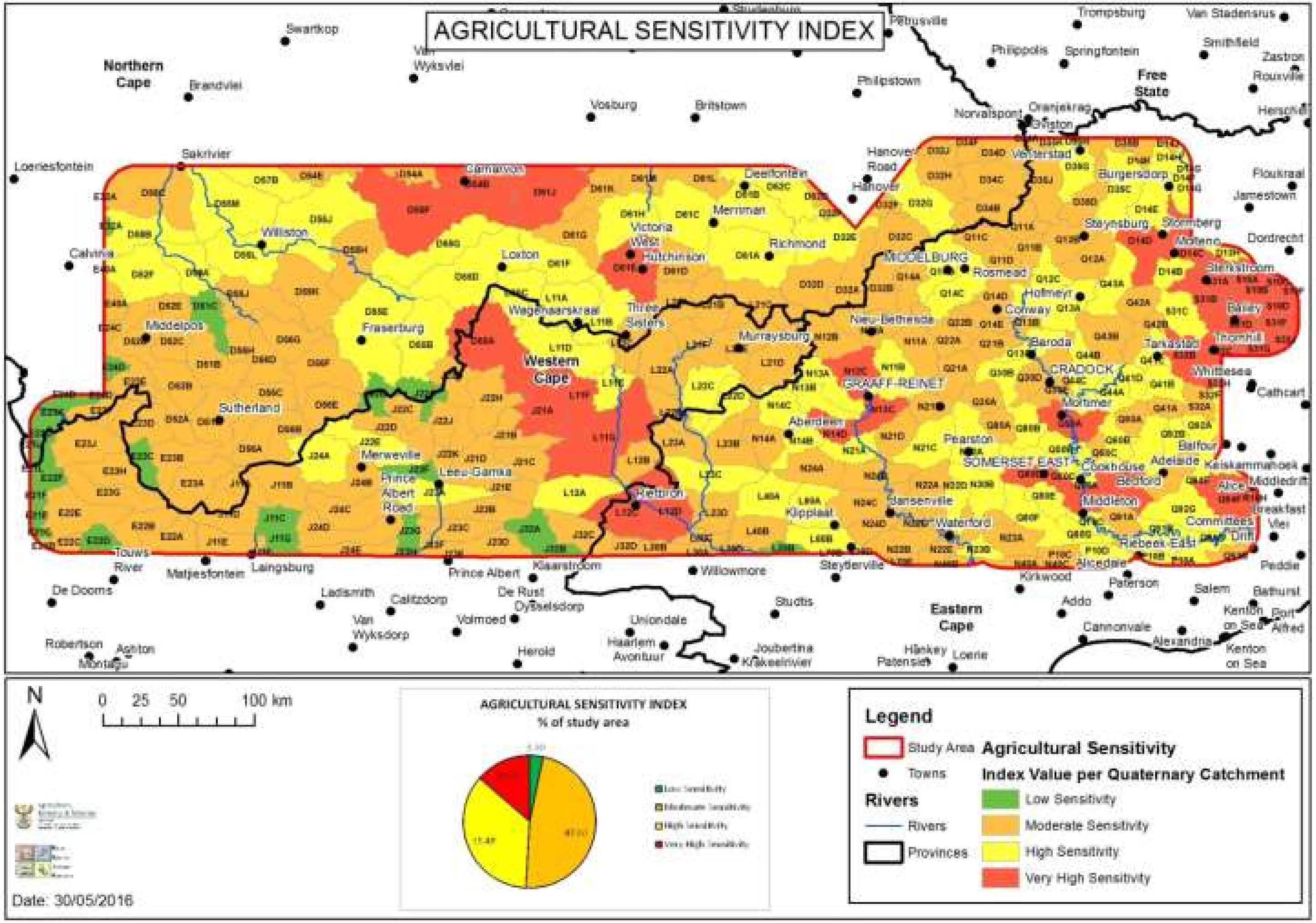


Figure SPM 8.1: Four tier agricultural sensitivity map focused on the study area within the Central Karoo.
The index considers land capability, grazing capacity, cultivated fields, irrigated areas and surface water features such as river and dams. The proportions of sensitive areas are provided as a percentage of the entire study area as follows: Very High Sensitivity = 22.14%; High Sensitivity = 33.8%; Moderate Sensitivity = 32.21% and Low Sensitivity = 11.86%. The sensitivity index rating was based per quaternary catchment located within the study area.

Any intervention that weakens current land-based livelihoods is likely to have a long-term impact on the resilience of both the area and its land users. Local land users draw on profound local knowledge to sustainably use vulnerable land-based resources. Fragmentation of the landscape to accommodate SGD must be carefully mitigated to minimise the negative impacts on the viability of agricultural enterprises. [§8.6.2, §8.8.2.1]

Some agricultural land may be taken out of production (leased or purchased) while SGD is underway, which could have a positive impact on the incomes of agricultural land users. This suspension of production would have a limited negative impact on long-term food security at regional scale as it would not be lost to production in the long-term, and may benefit from being rested from grazing. [§8.8.1]

Sufficient policy, legislation and regulations exist to protect the natural agricultural resources. The enforcement of these instruments remains a major stumbling block to sustainable agricultural resource use and prevention of their degradation. The institutional capacity, skills and knowledge to implement and enforce these measures are limited, especially at local level. [§8.3]

Local economic development associated with SGD will likely stimulate local markets for agricultural products. Significant numbers of locally-based staff of SGD companies will increase demand for agricultural products. SGD is likely to attract service enterprises that will also contribute to the local economy and consume agricultural products. [§8.8.1]

SGD will put the privacy and security of land users at risk. Currently land users enjoy high levels of control over the farm-based resources. This is in part a result of little through-traffic on most farms and relatively stable local populations. An influx new people associated with the Small and Big Gas scenarios may expose farm property and livestock to theft and increase vulnerability of local communities to crime and potentially violence. [§8.8.2.1]

Long-term monitoring and evaluation is essential to measure the effectiveness and efficiency of mitigation measures applicable to agriculture under all scenarios of SGD. The effective implementation of mitigation and rehabilitation measures is important to limit the negative impacts of shale gas operations and to ensure their continuous improvement. The effective implementation of a long-term monitoring programme depends on the availability of adequate resources, especially at the level of local implementation. The outcomes of these monitoring and evaluation processes must be fed back to relevant stakeholders to ensure continuous improvement. [§8.8.2]

9. TOURISM IN THE KAROO

Tourism adds over R2 billion to the economy of the study area annually. Tourism provides the largest number of enterprises in the study area: 828 in 2015/16, employing between 10100 and 16400 workers and annually adding R2.3 billion to R2.7 billion to the local economy. It is the fastest growing economic sector in most Karoo towns, thus its importance in the study area is expected to increase further in future, even in the absence of SGD. All towns in the study area are reliant on tourism, some (Nieu-Bethesda, Prince Albert, Sutherland, Loxton, Jansenville) more so than others (Figure SPM 9.1) [§9.1.2]. The rural Karoo landscape is an important resource for specialised tourism niches, such as eco-tourism, agri-tourism, hunting and adventure tourism, which disperse tourism activities beyond the towns. Negative impacts on the Karoo tourism brand poses risks to different tourists and industries in different ways (see Table SPM 9.1).

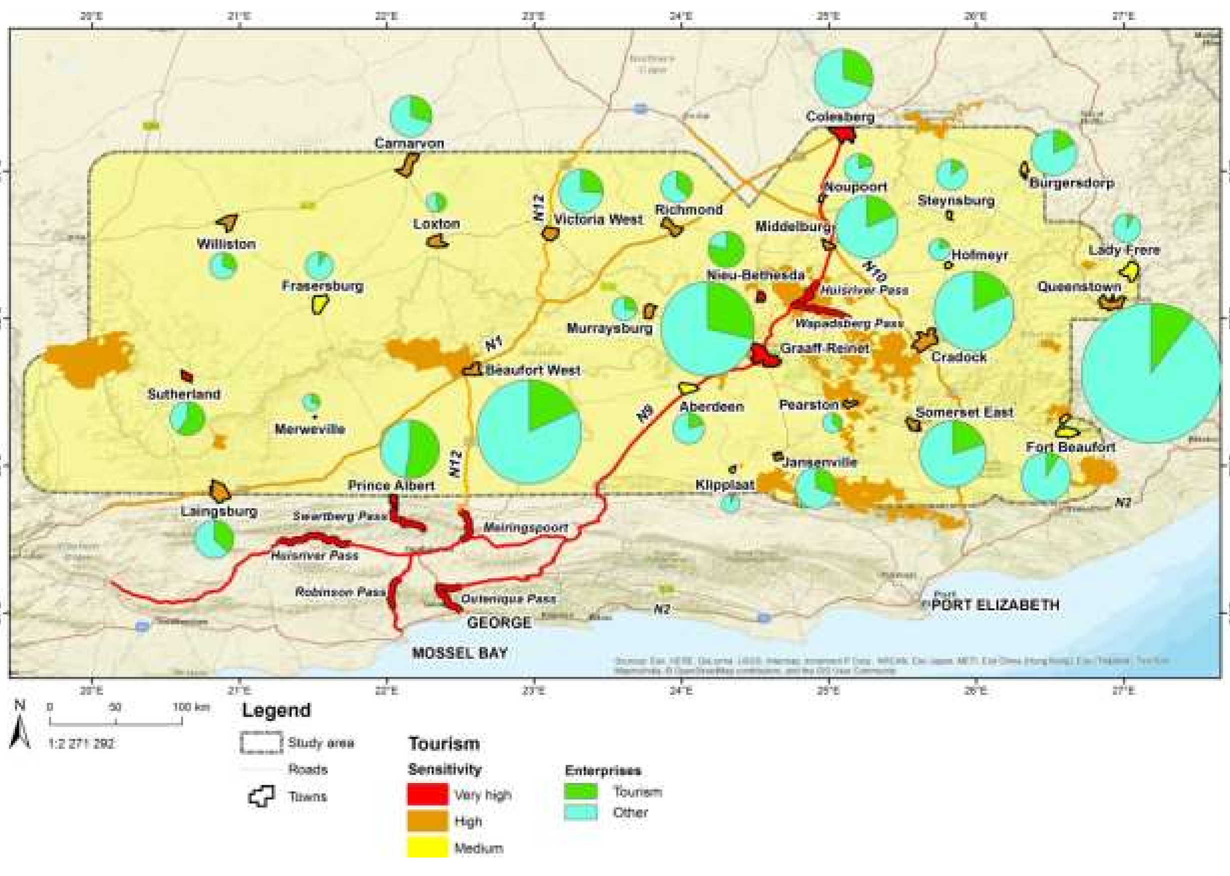


Figure SPM 9.1: Estimates of tourism sensitivity in the study area based on the number of enterprises. The estimate is determined based on the negative impacts on tourism and tourism enterprise numbers relative to the total number of enterprises of towns in the study area. Circle sizes indicate the total number of enterprises in each town.

The three broad tourist groupings identified in the study area have distinct requirements and different sensitivities with regard to SGD. The groups are: business tourists and those visiting friends and relatives (VFR); people travelling through the region; and niche tourists who actively seek out the Karoo as a destination for its landscapes, stillness, biodiversity, heritage, experiences, food and stargazing. Business and VFR tourism is expected to increase under SGD but might experience crowding out if shale gas workers use tourist facilities for accommodation in the towns, especially those of the N1, N6 and N9 routes. Tourists passing through the study area would experience an increase in traffic and, also possibly, competition for facilities in the towns. Niche tourists are most sensitive to disruption by SGD of the sense-of-place, biodiversity, and darkness and quietness of the Karoo. They are also the most dependent on rural areas (Figure SPM 9.1). [§9.2.1]

The most likely risk of SGD on tourism is expected to be an increase in traffic and its associated noise pollution. This would result from slow-moving trucks continuously ferrying materials needed for SGD, hindering traffic flows and traffic noise disturbances of tourists in towns and rural areas of the study area. It will start should exploration be initiated ca. 2018 and will escalate and endure should the Small or Big Gas scenarios happen from about 2025 to beyond 2050. Other risks include the visual disruption of scenic landscapes, a loss of sense of place, perceived or actual pollution (especially of water) and small earth tremors. All of these changes could impact on the value of the Karoo brand, which is associated with an undeveloped rural landscape. In regions of very high, high and medium sensitivity for the Small and Big Gas scenarios risks range from high to very high without mitigation. With mitigation, these risks can be slightly, although not substantially, reduced. [§9.2.3; §9.3]

Negative impacts on the tourism sector would increase the risk of losses of employment and value addition to local economies. The loss in employment and Gross Value Added (GVA) associated with various degrees of tourism impairment are provided in Table SPM 9.1. [§ 9.2.2] Negative impacts on tourism could endure for a decade or more after all SGD activities have ceased and full rehabilitation has been achieved.

Table SPM 9.1: Quantified losses in tourism enterprises, employment and value addition which could be experienced.

These may be associated with increasing levels of negative impacts caused by SGD.

Loss in tourism enterprises	**Tourism employment**	**Loss in GVA R million**
	Loss	
< 4%	<530	<100
4 - 8%	531 - 790	100.1 - 200
8.1 - 12%	791 - 1580	200.1 - 300
12.1 - 16%	1581 - 2110	300.1 - 400
16.1 - 20%	2111 - 2660	400.1 - 500
>20%	>2660	>500

Mitigating the risks on tourism requires active cooperation between the mining and tourism industries. Mitigation actions could include: (i) Protecting key tourism access routes, for instance the N9, from the heavy truck traffic associated with SGD; (ii) Limiting shale gas traffic on mountain passes (such as the Swartberg, Outeniqua, Wapadsberg, Lootsberg, Huisrivier and Robinson) that provide access to the area and enhance tourist experiences; (iii) Minimised heavy traffic on local tourist routes;. (iv) Protecting Karoo towns from impacts of SGD, especially those highly dependent on tourism; (v) Reduction of noise and visual disturbances in the study area through the use of appropriate buffers around sensitive tourism assets, such as tourist facilities, protected areas and heritage sites in the rural landscape; (vi) best practice mitigation of air, water and light pollution. [§9.3]

Integrated tourism management would be required to deal with the complexities resulting from SGD. Management of tourism in the study area is currently fragmented between three provinces and many municipalities, each with its own approach. A government-led or endorsed partnership with the mining and tourism industries to collaboratively protect and promote tourism in the Karoo is an example of an integrated approach. This could lead to the establishment of an appropriate institution to achieve integrated tourism management and to support the Karoo tourism brand. This institution could be funded by a levy on gas production earmarked to offset the negative impacts on tourism. [§9.3.4]

10. IMPACTS ON THE ECONOMY

SGD could deliver highly significant economic opportunities, but its extractive nature could also bring economic risks. In both respects SGD is little different to other types of mining. The opportunities include an increase in the national and local economic activity and employment. The principal risks relate to the 'boom and bust' nature of extractive industries, and to the effects of large new inward investments on increasing the value of the South African Rand, which can make exports less competitive. [§10.2]

Positive macro-economic impacts particularly on the balance of payments can be expected from SGD. Shale gas at prices at or below imported gas would in the medium term substitute for imported gas, which would improve the trade balance and shield the country from price volatility and exchange rate risks associated with imported natural gas. If the Big Gas scenario is assumed, gas revenue could be equivalent to between 8% and 16% of the current account deficit thereby making a potentially substantial contribution to deficit alleviation. The economic risk associated with exchange rate appreciation is considered manageable for the scenarios considered. [§10.2.1.2]

The achievement of long-term macro-economic benefits will necessarily depend on the uses to which the proceeds of SGD are put. Concerted efforts will need to be directed at ensuring that the majority of proceeds accruing to government are invested so as to enhance the long-term prospects of the country. [§10.2.1.1, §10.2.1.2]

Measures focused on ownership/shareholding, purchasing, hiring and training are the key ways in which the benefits of SGD can be maximised, both in the study area and nationally. These could include, for example, applying rules similar to those required in the enhanced Social and Labour Plans (SLP) in the mining industry and local community development requirements of the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP). [§10.4]

Shale gas development would increase employment opportunities. The Big Gas scenario would be associated with approximately 2 575 direct operational jobs in drilling, trucking and power generation with residents of the study area probably able to fill 15% to 35% of these positions initially, increasing over time as training proceeds (Table SPM 10.1). It should not be assumed that indirect and induced impacts in terms of jobs in the study area would reach the same level as direct impacts. [§10.2.2.2]

Table SPM 10.1: Preliminary estimate of direct employment opportunities resulting from shale gas development per scenario.

	Seismic exploration	**Exploration and appraisal drilling**	**Small Gas**	**Big Gas**
Size or recoverable reserve (tcf)	N/A	1	5	20
Use of gas resource	N/A	Potential movable modular power plants (1-2 MW each)	One 1 000 MW CCGT power station in the study area	Two 2 000 MW CCGT power stations in the study area and a 65 000 bpd GTL plant at the coast
Duration of activity (years)	1	5 to 10	35 minimum	35 minimum
Number of rigs/areas	5	5	3	20
Jobs per rig/area	100 to 150	100	100	100
Exploration and drilling jobs*	500 to 750	500	300	2 000
Transport/trucking jobs**	N/A	20	40	275
Power station jobs (by 2050)***	0	0	80	300
Total eventual jobs (regardless of where employees are from)	500 to 750	520	420	2 575
Initial percentage of employees from within the study area	20%	15% to 35%	15% to 35%	15% to 35%
Initial number of employees from within the study area	100 to 150	80 to 180	60 to 145	390 to 900

* Total exploration and drilling jobs were estimated in Burns et al. (2016)

** Transport/trucking jobs based on truck trip numbers in Burns et al. (2016) (these are substantially greater for the Big Gas scenario given the larger number of wells), assuming two drivers per truck and two return trips per eight-hour shift.

*** Power station jobs based on current jobs at larger Eskom power stations which are gas-fired or could be gas-fired such as Ankerlig and Gourikwa.

SGD would be a new economic activity in the study region of a potentially similar magnitude to the emerging renewable energy sector. Table SPM 10.2 provides a comparison of SGD impacts on jobs and value generation to those associated with the agriculture and tourism sectors and the renewable energy projects in the study area. It provides broad context for evaluating potential impacts. It shows, for example, that the Small Gas scenario for SGD should result in roughly half the direct jobs expected from the currently approved renewable energy projects, while the Big Gas scenario should exceed these jobs by a factor of at least three. [§10.2.2.2]

Table SPM 10.2: Estimates of direct operational employment and economic contribution by the main economic sectors in the Central Karoo. Also included are the approved renewable energy projects relative to SGD.

Sector or project	**Direct operational jobs for people from within the study area**	**Broad indicators of economic value within the study area**
Agriculture*	38 000	Total Gross Farm Income (GFI) of R5006 million/yr. Contribution of activities directly related to hunting equalling R189 million/yr
Tourism*	10 100 to 16 400 jobs	R2.3 billion/yr to R2.7 billion/yr contribution to annual study area Gross Value Added
Shale Gas Development	Initially 60 to 145 for the small scale production or 390 to 900 for the Big Gas scenario	R3.5 billion/yr to R7 billion/yr turnover for small scale production scenario or R14 billion/yr to R28 billion/yr turnover for large scale production
Renewable energy projects**	Initially 115 to 270 assuming that the portion of jobs that go to local residents is same as for SGD	R3.75 billion/yr to R4.75 billion/yr turnover

* From Oettle et al. (2016) [Agriculture] and Toerien et al. (2016) [Tourism].
** Jobs estimates based on capacity (totalling 1 500 MW) of 14 preferred bidders/projects approved for the study area under the REIPPPP multiplied by jobs/MW averages for wind and solar power projects contained in the 'Green Jobs' report (Maia et al., 2011). Turnover estimates based on capacity per project multiplied by capacity factors for wind and solar published by NERSA and by contract prices per bidding round published by DoE.

The risk that SGD could 'crowd out' other economic sectors in the study area, such as agriculture and tourism, by causing rises in the prices of labour and other inputs, is low for the scenarios considered. An important proviso is that SGD should not seriously compete with local water users or pollute local water supplies. [§10.2.2.2.2]

Local government finances are likely to be put under significant strain particularly under the Big Gas scenario. Appropriate mechanisms will be needed to effectively alleviate this strain. [§10.5]

For the Big Gas scenario, there is a high risk that the residual costs associated with SGD become the responsibility of society. With mitigation this can be reduced to moderate. Mitigation includes the implementation of financial mechanisms to ensure that developers make adequate financial provisions to allow the state to deal with remediating remaining impacts in the event of pre-mature closure and longer term risks associated with the post-closure period. [§10.2.3]

Adequate and unambiguous compensation mechanisms are needed for landowners to cover the use of their land and for other affected parties where environmental and other damages cannot

be mitigated. Property values on farms near where drilling occurs are likely to decrease – the risk is assessed as moderate without mitigation. This applies to places exposed to water supply or quality deterioration, and to places whose amenity value is reduced by visual, noise, traffic or security risks. This loss can be balanced by adequate compensation. Property values in towns, on the other hand, are likely to increase due to increased economic activity assuming key externalities such as those associated with increased truck traffic can be managed. [§10.2.4]

11. THE SOCIAL FABRIC

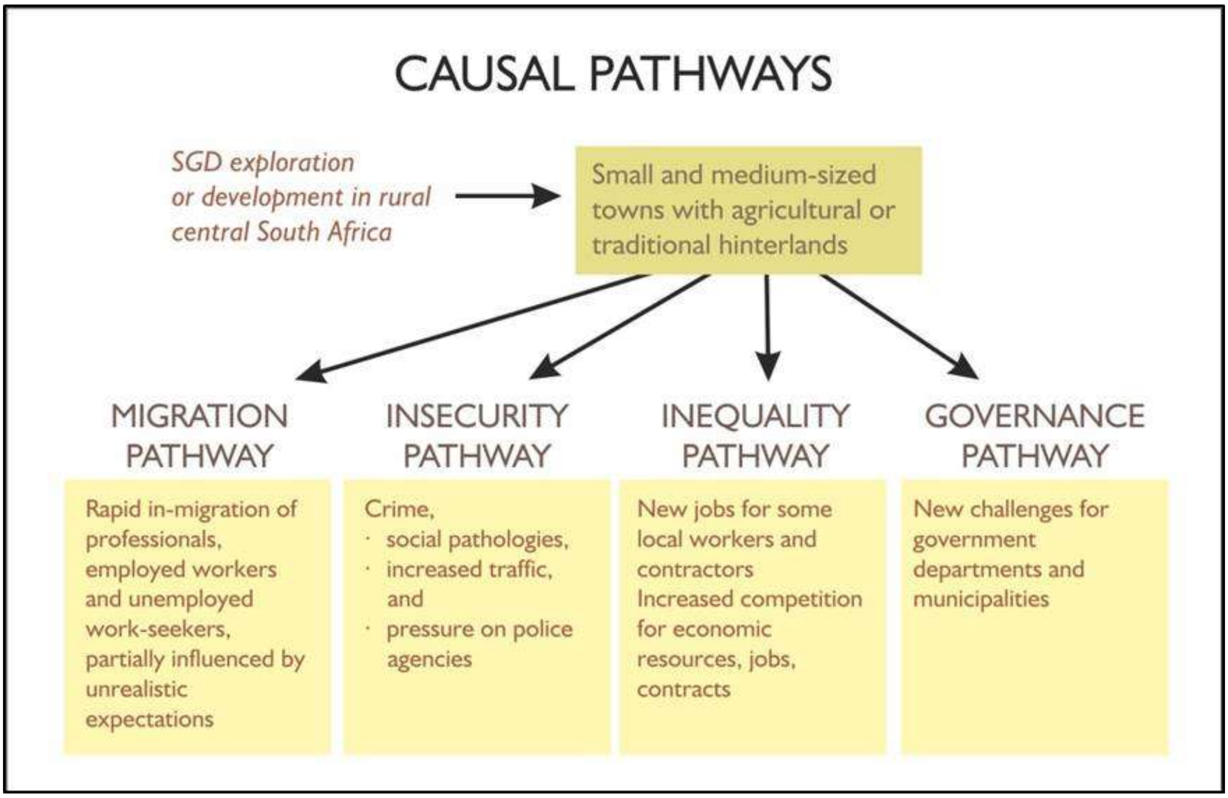


Figure SPM 11.1: Four main casual risk pathways of shale gas development which may affect social fabric. These are (a) human migration; (b) safety and security; (c) social institutions / inequality; and (d) governance. These are all interrelated in various ways, so they should not be considered in isolation.

For human migration, assuming the Small and Big Gas production scenarios, the risks will be high to very high respectively. This can be somewhat reduced to high with mitigation, for both scenarios. Mitigation efforts will include housing provision, training programmes and transparent employment practices. Municipal planning processes are typically slow and cumbersome, and therefore unable to respond timeously to these demographic fluxes. Towns in the study area already experience housing backlogs, due to inter-town and farm-town migration trends. Human in-migration to the affected environment can trigger inter-community conflict in competition for scarce resources, such as employment. If the Exploration Only scenario phase does *not* move on to the Small and Big Gas scenarios, there will be a sudden reduction in housing demand, and very likely an outflow of population. [§11.2, §11.3]

As regards physical security, assuming the Small and Big Gas scenarios, the risks are considered very high and high respectively. Various mitigation strategies are possible, depending significantly on the capacity of policing and social support agencies. Small towns in the study area will have to expand their traffic management capability significantly due to much greater traffic pressure caused by SGD trucking. With mitigation, risk can be reduced, but it is still considered to be high. [§11.2, §11.4]

There is a high risk without mitigation that benefits may not be equitably distributed, thus reducing the strength of local social institutions. For the Small and Big Gas scenarios, these risks can be reduced to moderate with mitigation. There may be more jobs and wages in the local community, stimulating new economic multipliers. This may be associated with increased competition for resources and xenophobia in a multi-racial society, disruption of local employment patterns, alienation, conflict and greater social inequality. Mitigation would include assisting communities in become more resilient and adaptable over time; however it is not clear how much institutional effort will be required by other government agencies, to promote resilience. Furthermore, proactive company initiatives may well strengthen local social institutions. [§11.2, §11.3.3, §11.3.6, §11.6.5]

Opportunities through large investments in small town areas create boomtown conditions in the local economy. SGD especially in the Big Gas scenario will create a significant mining sector in the study area. This will be associated with increases in construction, trade (wholesale and retail) and business services, which are likely to have extensive multiplier effects in the local economy, as well as job creation in these sectors. [§11.5]

In terms of governance and power dynamics, the risks associated with the Small and Big Gas scenarios are high. SGD, while anticipated to raise the mean social welfare at national and local level, may perversely simultaneously accentuate social inequalities and schisms. With mitigation in the Big Gas scenario, this risk can be reduced to moderate, but remains high for the Small Gas scenario. There may be increased pressures on already inadequate municipal governments to meet the growing demand for basic services, and new political tensions. Municipalities will be subjected to a wide range of demands for new or expanded services, and the administrative capacity, staffing levels, equipment, and outside expertise needed to meet those demands may be beyond anything that has been budgeted. The mineral leasing process typically involves experienced business people on one side and inexperienced farmers and municipalities on the other. This raises the risk that energy speculators will take advantage of local people, or that such perceptions are created, thereby detracting from municipalities' legitimacy. [§11.6]

12. IMPACT ON HUMAN HEALTH

The health status of the local population in the study area is currently below the national average, making them more vulnerable to adverse human health effects from SGD. This is despite the perception of the Karoo as a healthy environment, and is largely related to poverty, inadequate housing, unsafe water and sanitation, and insufficient health infrastructure. Investment in health infrastructure and improving socio-economic status, arising from SGD or other sources, could improve the health outcomes in the communities (Figure SPM 12.1). [§12.5]

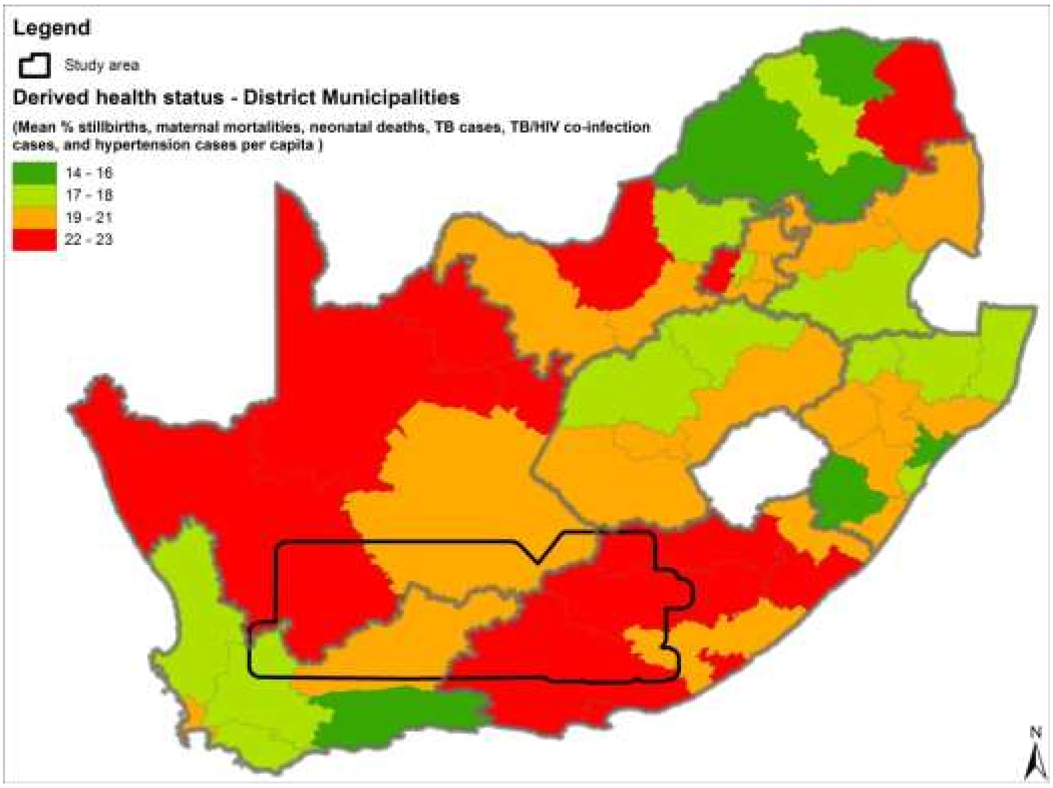


Figure SPM 12.1: Current health status of people in the Central Karoo compared with the national average. Based on numbers of still births, neonatal deaths, maternal mortality rates, TB and TB-HIV co-infection rates and hypertension per capita with red indicating highest percentage health issues.

People living close to shale gas infrastructure (wellpads and roads) are at risk of negative health impacts through air, water and noise pollution. Through on-site mitigation and keeping SGD operations at a safe distance from population centres, the potential human health risks on communities can be reduced to moderate, but some reduction in air quality will nevertheless be experienced at regional scale. [§12.2, §12.3, §12.19]

There is a high risk that SGD workers can be directly exposed to toxic substances for extended periods. Short-term dermal and respiratory symptoms are common among SGD workers. Some cases of death have been reported in countries with a history of SGD. Airborne silica exposure at the wellpad is an important cause of respiratory issues. Mitigation options, such as engineering solutions and personal protective equipment, conforming to the Hierarchy of Pollution Controls (Figure SPM 12.2), can substantially reduce the workers' exposure to moderate. [§12.10, §12.14]

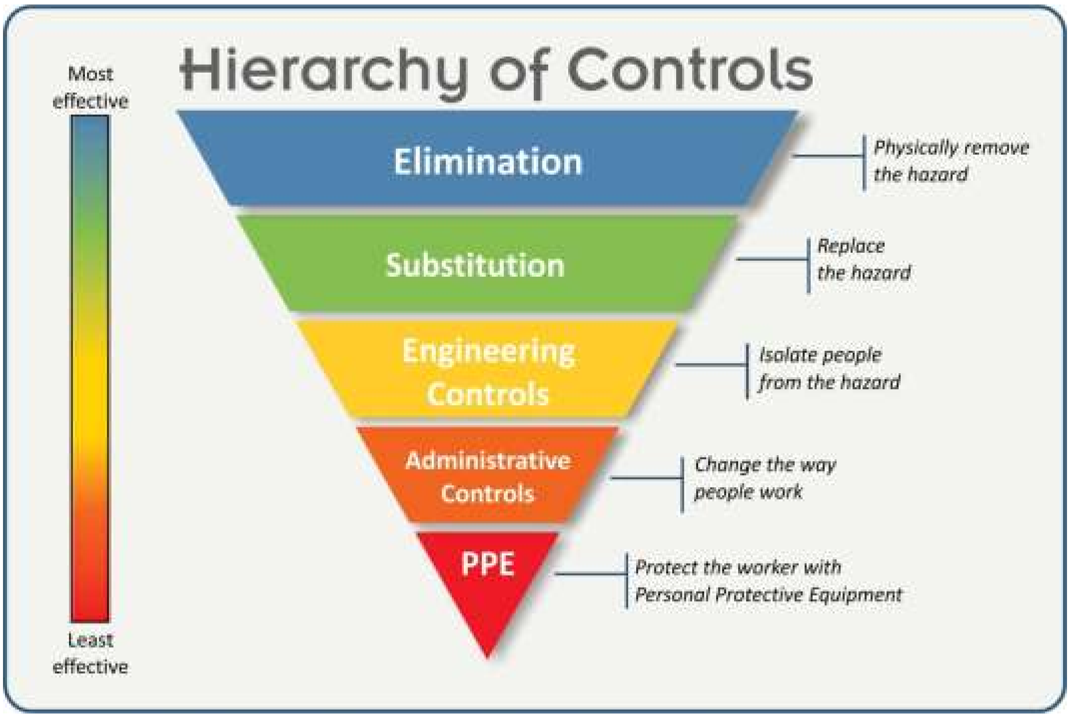


Figure SPM 12.2: Hierarchy of pollution controls for occupational health and safety for workers at sites of shale gas development.
This is particularly relevant to production sites associated with the Small and Big Gas production scenarios. (Source: NIOSH, 2015)

Baseline monitoring is crucial to attribute a future negative or positive impact of SGD on human health in the study area. Currently the available information on health issues in the study area is inadequate to form a baseline. Metrics such as incidence of asthma and other respiratory problems, dermal irritations (rashes), cardiac, cancer, birth weights, birth defects, APGAR scales, kidney and liver, infertility, neurological impairment need to be monitored. [§12.20]

Uncertainties in the chemicals to be used and their health consequences are the major limitation to assessment of the likely risks of SGD on health. This assessment is based on international data and experience. Many of the chemicals used in SGD do not have adequate health data associated with them to make an assessment. Since the activity of fracking worldwide is relatively new in relation to the time needed to assess long-term health effects, including trans-generational effects, robust scientific evidence is scant. Some of the chemical used are known to have long-term health effects. [§12.8]

Detection of health impacts resulting from SGD will require baseline and ongoing monitoring of air and water quality and health. A focus should be the health symptoms associated with SGD. A baseline will need to be established prior to initiating SGD activities in to enable unambiguous attribution of change to specific causes. Health issues should be included in the Regulations for Petroleum Exploration and Production, which currently do not consider them directly. [§12.7, §12.20]

13. SENSE OF PLACE VALUES

There is insufficient underlying research and documented evidence for this assessment to comprehensively evaluate the issue of sense of place. The assessment describes the key concerns and determinants with respect to sense of place, and is able to infer some limits of acceptable change for particular senses of place, based on the existing landscape and its land use. Sense of place has strong links to visual and noise impacts, social fabric and heritage and biodiversity issues, but also contains subjective elements which are not fully captured or measurable by those approaches. If these subjective elements are not researched and included in future SEAs or EIAs and other development processes then the risk of social disruption through SGD would increase.[§13.1, §13.2, §13.8]

There is not one, but are several, 'senses of place' in the Karoo. Some of them have local significance, while others are sensed by people living outside the area (for instance, by tourists), and perhaps even by people never visiting the area (for instance, the senses of place resulting from elements of scientific significance or artistic representation). The multiplicity of senses of place in this assessment have been identified in a generalised way from publicly available literature or media and potential areas of conflict or sensitivity highlighted .While this is not best practice or conclusive, it provides an indication of the range of sense of places that have been expressed in the public domain (Figure SPM 13.1). [§13.3, §13.5].

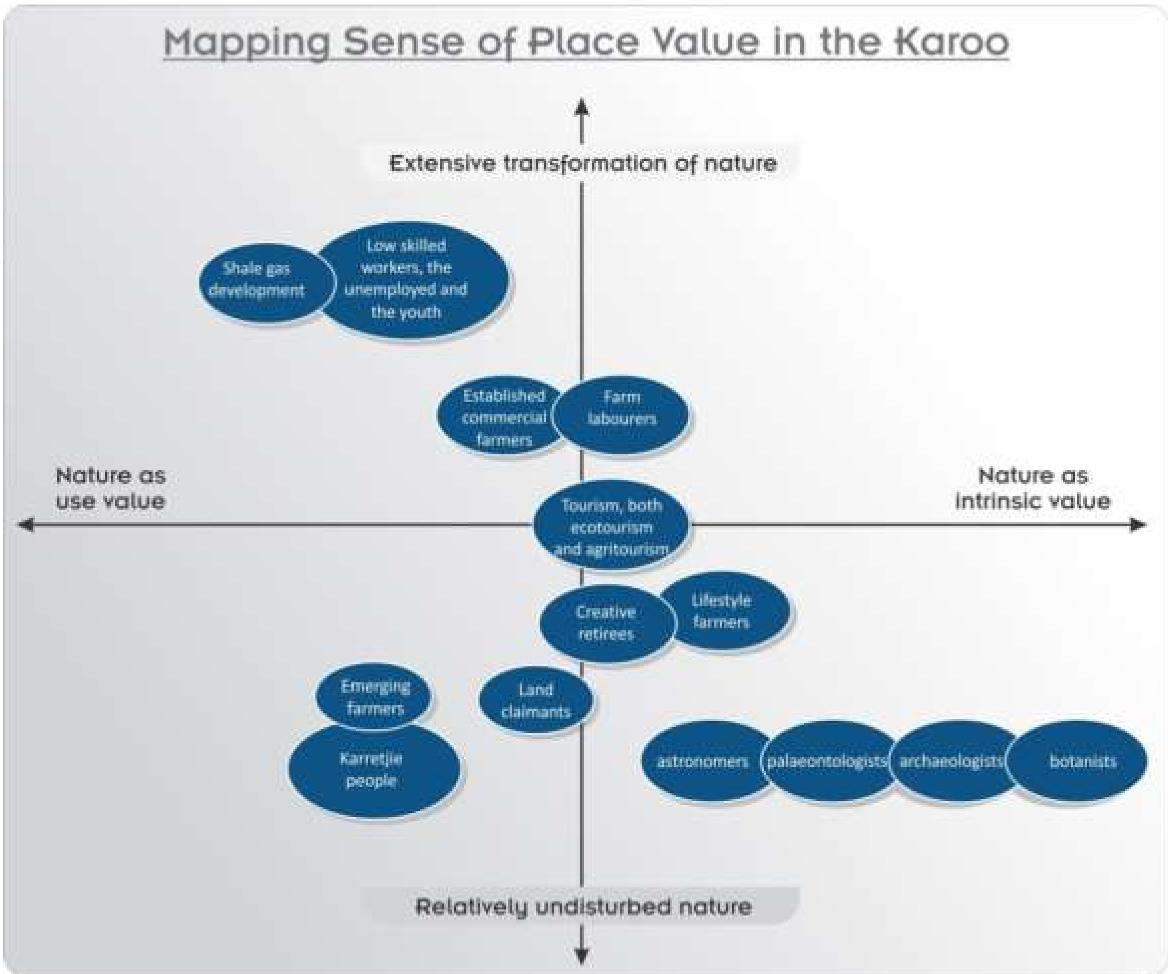


Figure SPM 13.1: Matrix of 'sense of place' values experienced in the Central Karoo.
Two of the key dimensions of the variation in sense of place in the study area are whether the sense of place is based on a human-transformed environment, such as towns or farmland, or on a minimally- disturbed landscape; and the priority which human extrinsic needs (such as employment and income) are given relative to intrinsic values such as aesthetic or spiritual appreciation.

SGD in the Karoo will affect values associated with sense of place, in some cases positively and in others negatively, and in some cases irreversibly. The loss of sense of place for farmers, farm labourers (including the Karretjie People), emerging farmers and land claimants ranges from moderate to high across the scenarios without mitigation and low to moderate after mitigation. The loss of sense of place to lifestyle farmers, creatives, retirees, tourists and scientists ranges from high to very high across the scenarios without mitigation and high to moderate with mitigation. The loss of sense of place to people associated with SGD, low-skilled workers and unemployed youth is considered very low with and without mitigation. [§13.5, §13.7]

Some senses of place are in conflict with one another whereas others are more compatible. It could be argued, for example, that shale gas developers employ a sense of place that is in conflict with the average Karoo tourist's sense of place that usually involves a sense of nothing or remoteness. Should SGD occur, a significant measure of this remoteness or "Niks" of the Karoo could be lost forever. However, for example, the tourism industry's sense of place and the farming community's sense of place are far more compatible and even supportive of each other. They both encourage low levels of noise, open space and limited numbers of people. [§13.1, §13.3.14, §13.5, §13.7.1]

Senses of place are not equally valid or justifiable within all contexts and some senses of place may have greater legitimacy than others. Senses of place are often shared by people who either live in a place or those who value it as a destination for work or holidays or who view it from an outsider's perspective. They may be regarded to have more value because they are shared by a greater number of people or potentially create value for a larger number of people. Others have more impact because it is the majority view of the people who own land and/or pay taxes and still others carry more weight because they are compatible with a diversity of senses of place. [§13.1, §13.7.2]

Sense of place values are seldom adequately addressed in public participation processes such as in EIAs, although they often turn out to be major issues. For them to be adequately addressed would require detailed empirical research to elucidate the specific sense of place values in particular contexts. One way to fill this critical gap would be to include such investigations in processes such as SEAs, EIAs, Spatial Development Frameworks (SDFs) and Environmental Management Frameworks (EMFs). It is recommended that both quantitative (Likert type surveys) and qualitative (ethnographic type fieldwork) research methods be applied to establish sense of place values within communities. This information would enable monitoring of change in senses of place and determination of the limits of acceptable change. [§13.6, §13.8]

14. VISUAL, AESTHETIC AND SCENIC RESOURCES

Without mitigation across the SGD scenarios, it is likely that visual fragmentation of Karoo landscapes, and transformation of its pastoral or wilderness character to an industrial connotation will occur. With mitigation which generally requires avoiding visually sensitive areas identified in Figure SPM 14.1; these risks can be reduced. Not all risks related to visual impact are mitigatable and very high residual risk may remain even with mitigation, especially in the high sensitivity areas and under the Big Gas scenario. [§14.4.4]

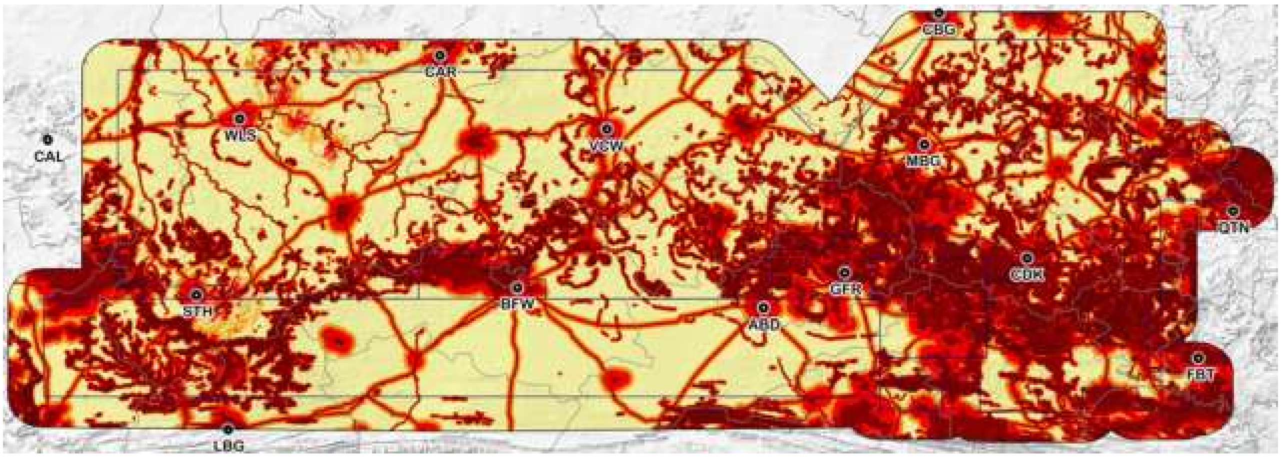


Figure SPM 14.1: Composite map of all scenic resources and sensitive receptors in the study area. This includes visual buffers, indicating visual sensitivity levels from dark red (the actual feature or receptor), red (high visual sensitivity) orange (moderate visual sensitivity) and yellow (low visual sensitivity). These are not necessarily exclusion zones, but indicate visual sensitivity at the regional scale.

Potential visual impacts resulting from the proposed SGD can be managed to a limited degree through a range of avoidance, mitigation and offset measures. Avoidance measures involve the protection of valuable scenic resources, including the use of visual buffers. Mitigation measures are mainly project-related, such as the control of construction activities and minimising the visual intrusion of structures in the landscape (Figure SPM 14.2). Finally, offset measures involve compensation in one form or another for the visual intrusion caused by SGD and possible loss of scenic resources. A possible offset is the creation within the study area of a scenic wilderness corridor forming a linked system of protected landscapes. [§14.4.1]

Cumulative impacts in the Central Karoo may pose a compounding risk. The visual risks of SGD must be considered in conjunction with visual risks resulting from associated secondary developments and from other unrelated developments in the study area, for instance the roll-out of wind and solar energy and possible uranium mining. Mitigation consists primarily of restricting SGD activities in visually sensitive locations [§14.4.1]

Scenic 'hotspots' in the Karoo that are particularly sensitive to SGD can be identified. These need to be taken into account in EIAs and other permitting processes. Currently, visual resources have no specific legal protection in South Africa, except under the definition of the National Estate in the

National Heritage Resources Act. It is advisable that national, provincial and local authorities enact legislation or by-laws to prepare for the effects of possible shale gas activities on visual resources (Figure SPM 14.1). [§14.4.2]

National, Provincial and Local Government need to prepare for future possible SGD in South Africa in order to conserve scenic resources and protect visually sensitive receptors. Best management practices to minimise potential visual impacts have been gleaned from similar activities in South Africa and from overseas studies on SGD. [§14.5]

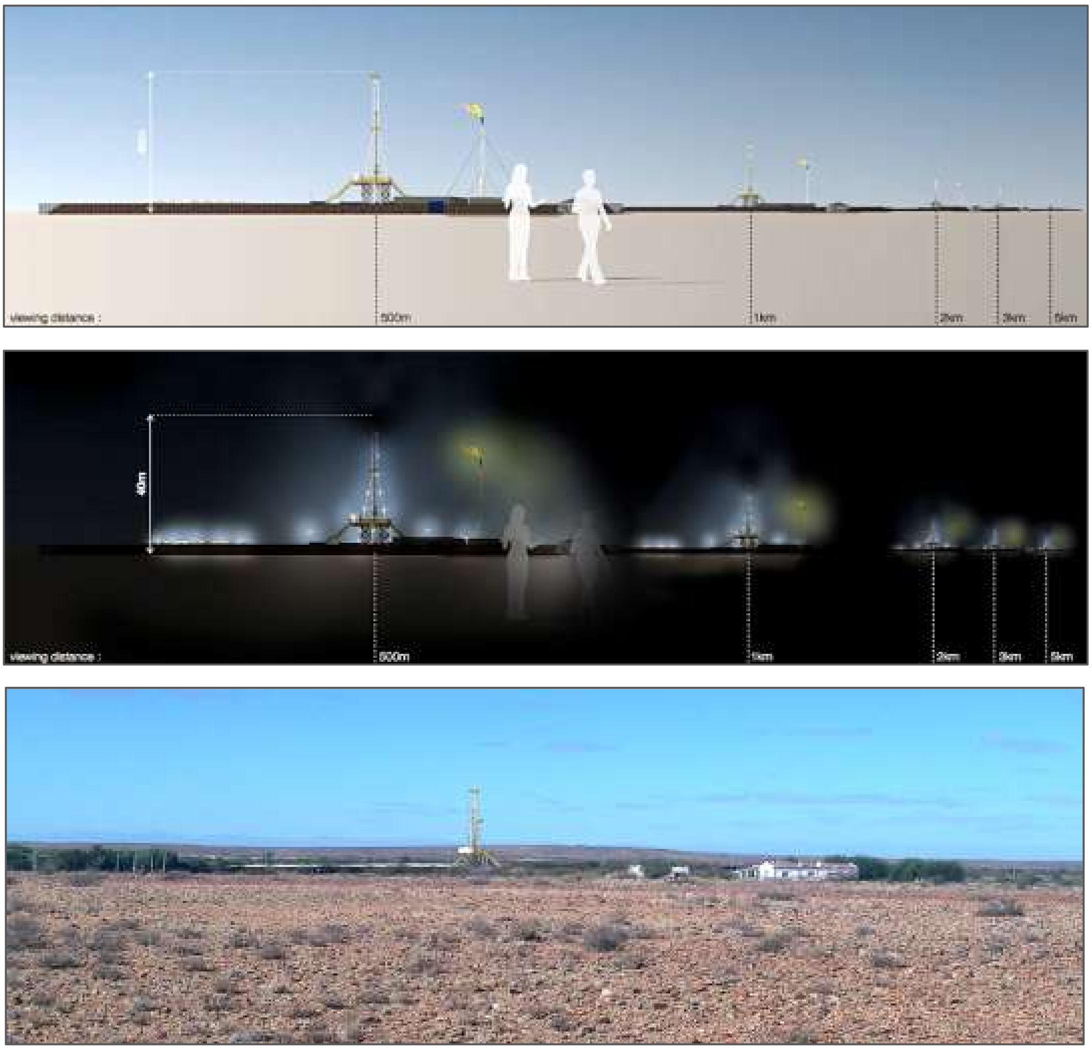


Figure SPM 14.2: Visual simulations of a wellpad located in the Central Karoo landscape.
During the day (top) and at night (middle) indicating visibility at a range of distances from 500 m to 5 km, before mitigation. The flatness and low vegetation in the Central Karoo enhances visibility. Night time visibility of lights would tend to be pronounced in the dark rural landscape of the Karoo. A visual simulation of a wellpad in a Karoo landscape at a distance of about 300 m (bottom). The adjacent farmhouse gives an indication of the scale of the drilling rig.

The level of information relating to scenic resources needs to be addressed; there being no comprehensive or standardised baseline or grading system currently in South Africa, nor fine-scale mapping for the study area. Additional information is required in particular for cultural landscapes and for private reserves, game farms and resort or tourism-related amenities that could be affected. An assessment of cumulative impacts would require information on the location and density of proposed SGD in relation to other existing and proposed activities, such as wind and solar energy developments, as well as uranium mining. [§14.6]

15. IMPACT ON HERITAGE RESOURCES

The risk to heritage resources from SGD varies markedly from place to place within the study area. It depends on the type of heritage resource, the specific locations of wellpads, access roads and related infrastructure, and the amount of induced seismic activity that occurs. There is no part of the study area where there is no risk to heritage resources. Heritage resources representing all levels of significance are distributed in variable densities throughout the study area, but because of generally low survey coverage the actual distribution of resources is poorly known. Living heritage, which is ubiquitous, binds the physical resources together and contributes to the character of a region that is so highly valued by a wide community of South Africans. [§15.1.1]

Heritage resources in the study area are part of the National Estate and thus belong to the people of South Africa. While most are of relatively low heritage significance, there are numerous sites of high sensitivity scattered across the region. Towns and villages, river valleys, rocky ridges and the undulating uplands tend to be more sensitive than the open plains for some categories of heritage, largely because of access to water. In these regions the risks to heritage resources is considered high but can be reduced to low by appropriate micro-siting of SGD infrastructure during EIA processes [§15.3.1]. Seismic activity could negatively affect heritage resources to varying degrees depending on the fragility of the resource, but built heritage within 10 km of fracking sites is considered a high risk without and with mitigation. [§15.2.1, §15.2.2]

The risk to heritage resources in the study area during the Exploration Only scenario is considered high. The exploration phase may be associated with intensive and widespread seismic lines and 3D surveys in the region. The Small and Big Gas production scenarios would be confined to designated 30 x 30 km production blocks, thereby reducing the risks associated with widely dispersed and diverse heritage resources. Although it will not be possible to choose the exploration and/or production areas based on heritage resources, micro-siting of the infrastructure and the implementation of management and mitigation measures during all phases will help reduce risks. The most difficult aspects with which to deal in terms of mitigation are aspects relating to the cultural landscape and, along with minimising the amount of landscape scarring that occurs, effective closure phase rehabilitation will be key to mitigating risks. [§15.4]

The risk to cultural heritage assuming the Big Gas scenario is considered very high without mitigation. For the Small Gas scenario it is high without mitigation. Avoiding the sensitive visual hotspots identified in the Visual Chapter by Oberholzer et al. (2016) will decrease the risk to high and moderate for the Big and Small Gas scenarios respectively (see Figure SPM 14.1). [§15.3.2.5, §15.3.2.7]

16. NOISE GENERATED BY SHALE GAS RELATED ACTIVITIES

Acoustic noise has a marked impact on the physical health of people and on their psychological wellbeing. The Karoo area is a quiet area. Residual day- and night-time noise levels are approximately 33 dBA and 25 dBA respectively (LAeq). This is 10 dB quieter than the typical levels published in standards for rural areas, a significant difference since an increase of 10 dB is perceived as a doubling of 'loudness'. [§16.1.2]

Exploration phase noise impact is likely to be localised and of short duration with very low risk with and without mitigation. Noise would be generated predominantly by trucks, and would only be noticeable in the immediate vicinity of exploration activities, for the duration of the activities. [§16.2.4, §16.2.5]

The Big Gas scenario will likely have very high noise risks for humans and animals within 5 km of the sites. Noisy activities during the operational phases are expected to run constantly (day and night) for six to eight weeks at a time, repeated every six months at every wellpad, for a period of a decade or two, with quieter activities between. Night time noise impacts are therefore most likely, when residual noise levels are at a minimum. [§16.2.4, §16.2.5, §16.3.3] For receivers within 5 km of drilling activities, the risk can be mitigated to high by implementing best practice management technologies. [§16.4]

For all scenarios, risk is reduced to very low once receivers are located a horizontal distance of 5 km away from drilling activities on wellpads. That being said, proposed sites of noise generating activities will need individual Noise Impact Assessments in accordance with SANS 10328 to determine the likelihood and severity of impacts at a site specific level. Noise control, attenuation and monitoring will likely be required for all sites. The extent of the required measures will be determined by the Noise Impact Assessment undertaken as part of an EIA process. [§16.5]

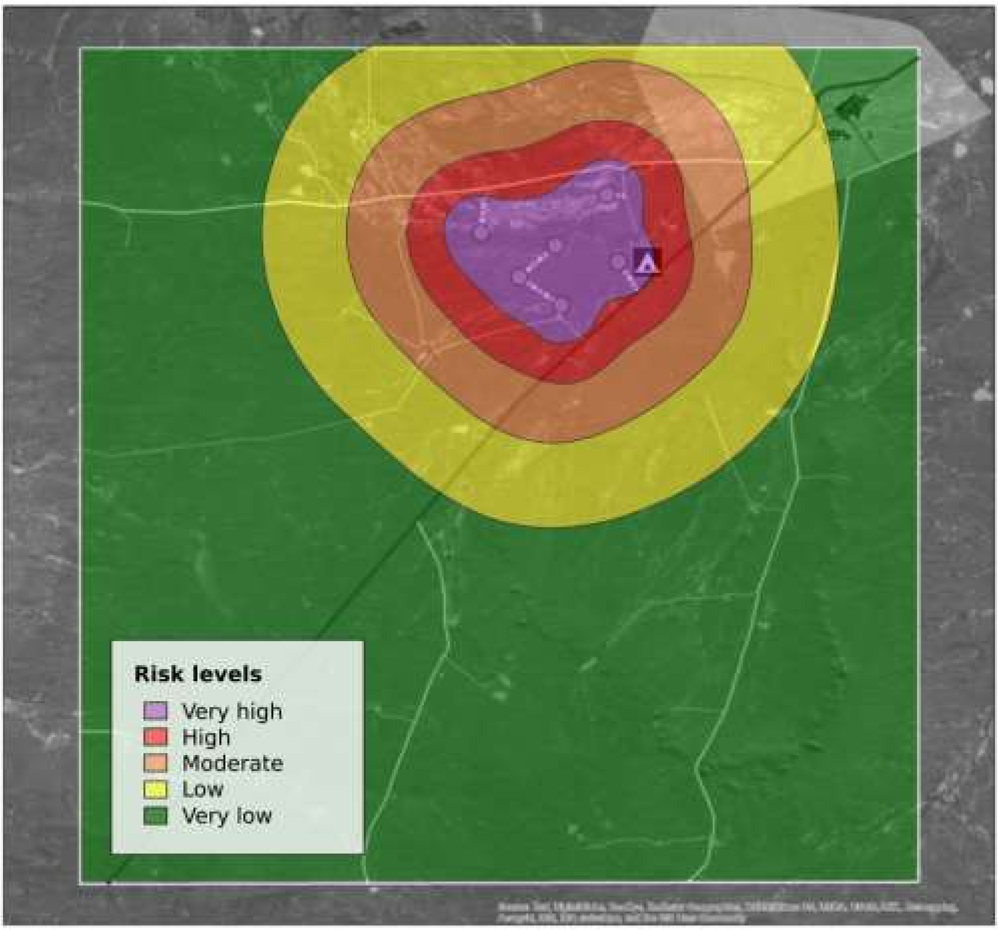


Figure SPM 16.1: Notional schematic showing the risk profile of noise impacts from wellpad activities. Risk reduces to very low once approximately 5 km from the wellpad. The figure does not include potential disturbance due to increased road traffic noise if roads are otherwise quiet.

There is additionally a risk of noise impacts emanating from the surrounding roads due to increased heavy goods vehicle road traffic. This will be especially prominent assuming the Big Gas scenario wellfield is located in the vicinity of quiet and seldom used roads. [§16.2.4] Under the Big Gas scenario, this risk is considered high without mitigation and moderate with appropriate traffic noise control mitigation applied. [§16.2.6. §16.4]

17. ELECTROMAGNETIC INTERFERENCE WITH THE SQUARE KILOMETRE ARRAY

The permissible electromagnetic interference (EMI, 'noise' in the radio frequencies) is regulated for those parts of the study area which can affect the performance of the Square Kilometre Array (SKA) radio telescope. The SKA will be the largest and most sensitive radio telescope in the world and constitutes a multi-billion Rand, multi-decadal investment, centred near Carnarvon, just north of the study area. The array forms a spiral with several arms, with receivers at increasing spacing on each arm (Figure SPM 17.1). Three of the spiral arms penetrate the study area. In terms of the Astronomical Geographic Advantage Act and its regulations, EMI at each of the distributed receivers may not exceed certain limits. [§17.1.1]

Electrical motors, switchgear, spark-ignited engine motors and communication devices are the types of equipment used in SGD which can potentially cause EMI. [§17.3.4] The first mitigation action is to reduce the number of such sources, and to select the equipment or shield it in such a way to minimise the EMI. Testing of all equipment for compliance is necessary prior to SGD. The EMI produced depends on both the specific equipment and its use. It cannot be assessed in detail at the strategic level, but when specific proposals are considered in an EIA phase, an inventory must be made, including where, how often and how many of each type will be used and the EMI characteristics of the proposed equipment must be determined. Radio propagation models can then be run to confirm that the specified limits are not exceeded at the receivers. [§17.3.7]

The key mitigation is to exclude EMI-generating sources for distances up to 40 km for the most sensitive parts of the SKA. Within sensitivity class 5 and within the Karoo Central Astronomy Advantage Area (KCAAA), no SGD activity is permitted (Figure SPM 17.1). If SGD activities are located beyond the KCAAA, but still fall within sensitivity classes 1-5, any activity would require detailed site specific EMI assessments. If mitigation actions are followed, the risk of EMI with the SKA originating from SGD is very low. [§17.3.5, §17.3.6]

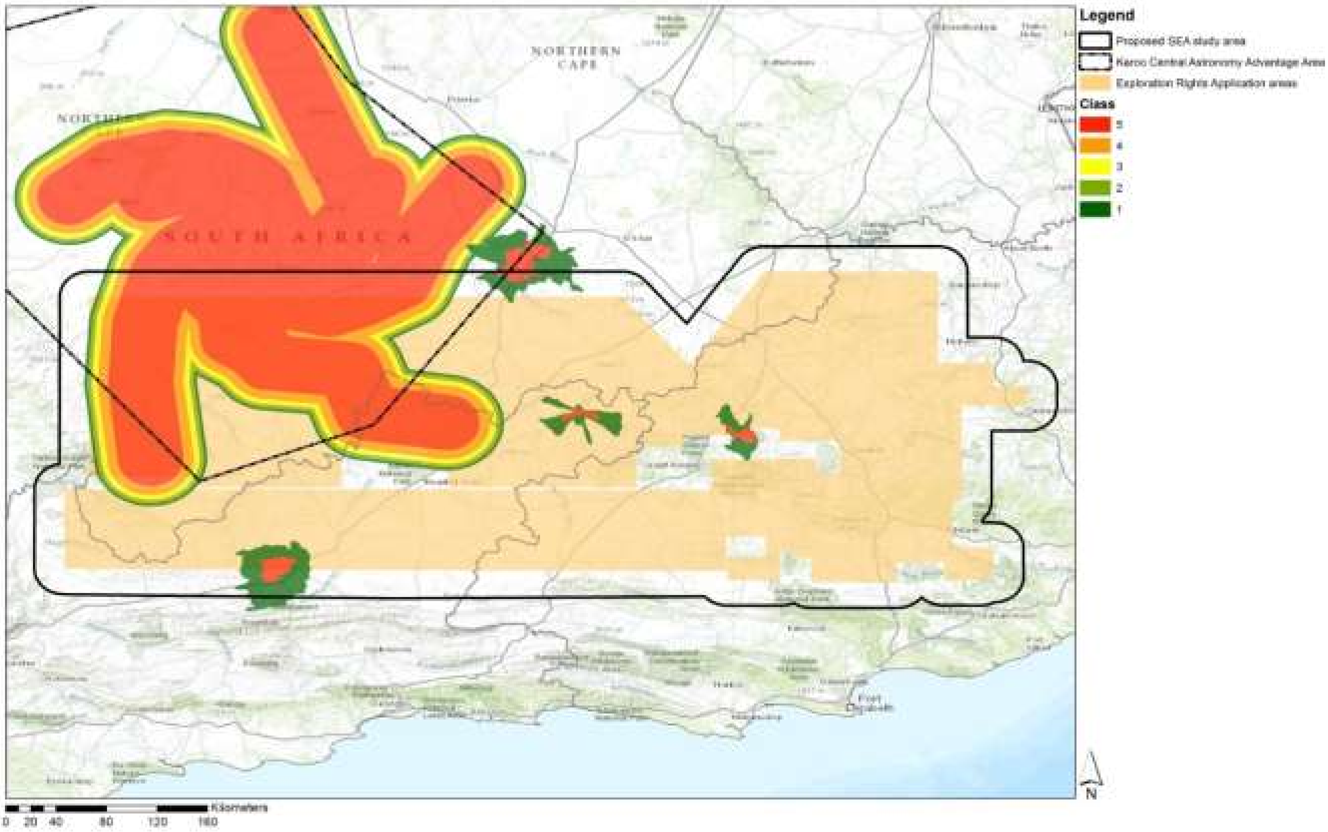


Figure SPM 17.1: Map showing the sensitivity classes of the Square-Kilometre Array.
The sensitivity classes are categorised from 1 – 5, where each class is informed by a specific separation distance. The KCAAA is shown as the black polygon around the SKA spiral arms, overlayed with the study area. The isolated polygons occurring outside of the core spiral arms and KCAAA are future planned antenna. Fracking activities beyond the pre-identified buffer zones do not represent a risk of detrimental impact on the SKA as a result of EMI. Within each sensitivity class, a particular level of EMI mitigation is required, which may make certain SGD activities unfeasible within sensitivity class 5. [§17.3.7]

18. SPATIAL AND INFRASTRUCTURE PLANNING

Towns in close proximity to SGD activities will experience growth exceeding projections based on past trends. For the Big Gas scenario, the risk is assessed as high, but can be mitigated to moderate. Enhanced resource and institutional capacity to plan for and address increased service delivery demand for housing, water provision, social services, electricity and roads will be required. [§18.2.3; §18.3.1, §18.4.5, §10.4]

Around 45 000 to 2 117 000 truck visits may be required for the Exploration Only and Big Gas scenarios respectively. For the Small Gas scenario the range will be somewhere closer to 370 000. The risks associated with the increased traffic volumes and new network of geographically scattered private local access roads and wellpads is considered high without mitigation. Mitigation will be required to source construction material and identify and approve local sites for extraction of raw materials. The risk can be reduced to moderate with mitigation. This would include adequate road rehabilitation prior to SGD, avoidance of certain routes; and improved safety and emergency response capacity. [§18.2.1, §18.2.4, §18.3.1]

There may be a need to develop pipelines and re-establish rail infrastructure in the sub-region to relieve the pressure on the road infrastructure. There is thus a critical need to audit and establish the current baseline condition and usage of national, regional and local roads to inform mitigation responsibilities in future. The current state of road infrastructure is generally poor and the financial and human capacities to address the issue are currently limited. [§18.2.2, §18.3.1, §18.4.2, §18.4.4]

Regulatory uncertainties and limited municipal capacity to facilitate ongoing processes of land use and land development applications associated with SGD poses a high risk without mitigation. This risk primarily relates to the already limited municipal governance capacity and regulatory bottlenecks. With mitigation, this risk can be reduced to moderate. Clarification of legal and implementation practices in the land use and land development regulatory framework, as well as provincial support to municipalities is required. [§18.2.4, §18.4.6]

The primary option for mitigation of risk is to enhance integrated spatial planning. This will be essential to deal with the multi-scaled and inter-sectoral issues that result from activities of magnitude and duration of SGD. SDF and IDP plans in the area will require updating. Given a number of other activities proposed in the area such as renewable energy projects, the SKA, uranium mining, transport corridors etc., the preparation of a Regional Spatial Development Framework could contribute to pro-active intergovernmental planning between the respective local and district municipalities, provinces, relevant provincial and national sector departments and other role players (Figure SPM 18.1). [§18.1.4, §18.4.1, §18.4.6, §18.4.7]

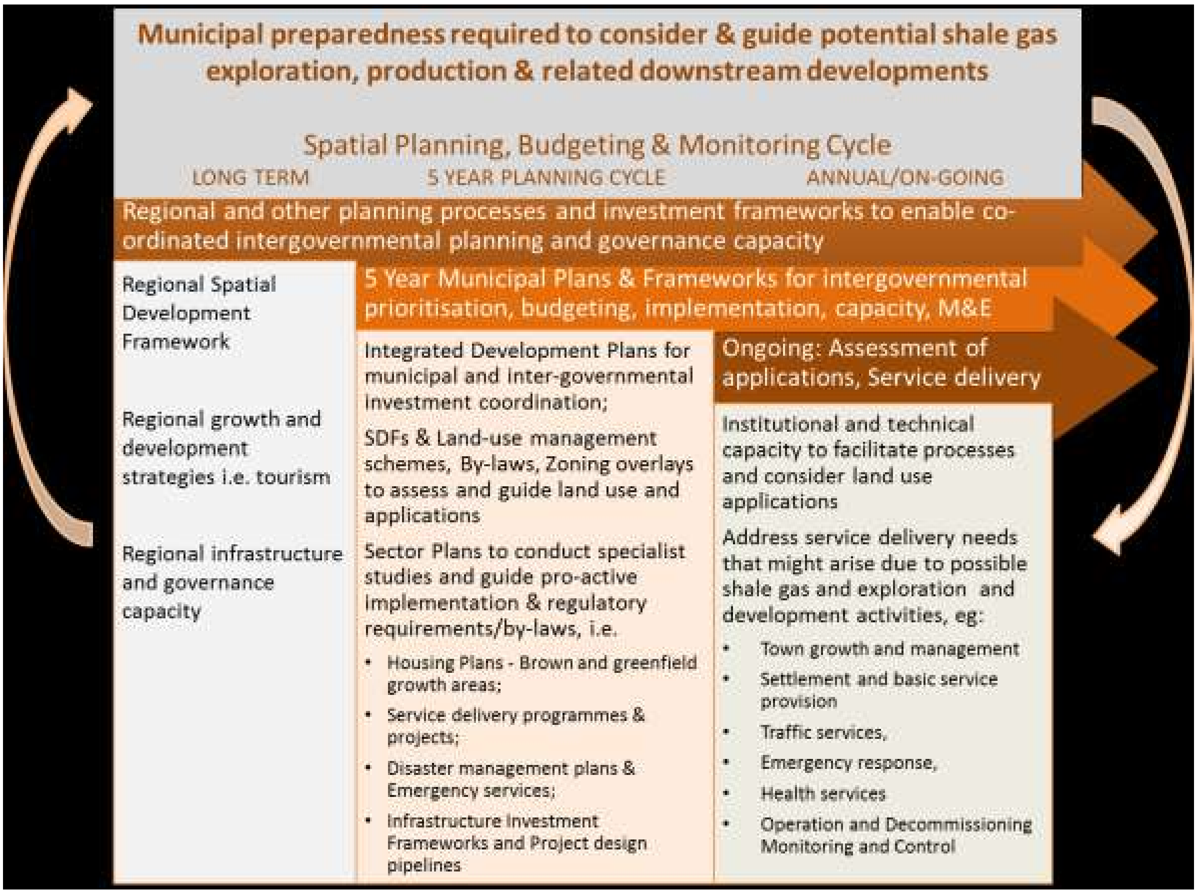


Figure SPM 18.1: Proposed system for developing enhanced municipal preparedness required to consider and guide land use applications, manage municipal impacts and service needs.

19. AN INTEGRATED 'RISK PICTURE'

Risks are assessed across the scenarios, with and without mitigation. Without mitigation assumes inadequate governance capacity, weak decision-making and non-compliance with regulatory requirements. With mitigation assumes effective implementation of best practice principles (including avoidance of key sensitive features), adequate institutional governance capacity and responsible decision-making. Based on the risk assessment approach described in the introductory text, risks are predicted in a consistent manner across the Chapters, ascribing a risk category to a specific impact, within a particular spatial setting (see Table SPM 0.1).

Some impacts assessed have spatially explicit risk profiles which have been integrated. For other Chapters, the impacts assessed do not have a specific spatial profile, such as those concerning social fabric, sense of place, energy planning, economics and others. This does not make the information contained therein any less relevant or important for decision-making.

An integrated 'risk picture' was developed (see Figure SPM 19.1). This picture spans the three scenarios (considered against the Reference Case) and assessments are made without and with mitigation applied. Spatially explicit risk profiles were merged, and are depicted using the 'maximum rule' to prioritise the highest risk areas over those of lower risk in the cumulative spatial overlay (see Table SPM 19.1).

The risk picture is not a detailed reflection of 'reality'. The purpose of the risk mapping exercise is to demonstrate the potential evolution of the risk profile across the scenarios considered, which accounts for the full life-cycle of SGD activities, from cradle-to-grave, and to test the efficacy of mitigation actions in reducing risks. The purpose of the risk picture is not to determine areas which should be excluded from SGD activities in the future, although more localised sensitivity mapping processes may reveal this with relatively high degrees of confidence in the future.

Table SPM 19.1: Chapter topics with spatially explicit risk profiles used to develop the integrated risk 'picture'.

Topic	Impact	Spatial unit
Air quality and Greenhouse Gas Emissions	Local community exposure to air pollutants	Sensitive areas identified as being within 10 km of towns
Earthquakes	Damaging earthquakes induced by fracking	Sensitive areas identified as a being within 20 km of towns
*Water**	Contamination of groundwater resources through surface spills and discharge	Water resource sensitivity maps developed based on legislated and proposed setbacks from surface and groundwater resources and associated geological structures
	Contamination of groundwater resources caused by a loss of well integrity and via preferential pathways caused by fracking	
	Physical disturbance of watercourses and contamination of surface water resources through flowback discharge and contact with contaminated groundwater	
*Biodiversity and ecology***	Ecological and biodiversity impacts	EBIS classes defined at habitat to landscape scales generally utilised in spatial biodiversity planning
Agriculture	Alteration of agricultural landscape and impact on agricultural resources base	Agricultural sensitivity classes defined at the quaternary catchment scale
Tourism	Tourism impacts	Tourism sensitivity classes defined at town, protected area, and tourism route scale
Visual	Visual intrusion into the landscape, altering the rural character	Visual sensitivity classes defined at the regional scenic resource scale
Heritage	Impacts on built heritage, monuments and memorials	Sensitive areas identified as being within 10 km from towns
	Impacts on archaeology and graves	Archaeology and graves sensitivity classes defined at the landscape scale.
	Impacts on palaeontology, meteorites and geological heritage	Palaeontology, meteorites & geological heritage sensitivity classes defined at a landscape scale
*Electromagnetic Interference****	Electromagnetic interference impacts on radio astronomy receptors (SKA)	EMI sensitivity classes defined at the scale of separation distances from the SKA development footprint

* The primary mitigation measure assumed for the 'with mitigation' assessment for water resources is that SGD activities do not occur within the areas mapped as being of high sensitivity (see Figure SPM 5.2). The spatial risk assessment must be interpreted in the light of known mapping constraints, with particular regard to scale.

** For biodiversity and ecosystems, 'with mitigation' assumes the following: 1.) That proclaimed protected areas are 'no-go' areas 2.) That EBIS-1 areas are avoided 3.) That EBIS-2 areas are avoided, or at a minimum, utilised but only following securing suitable offset sites in EBIS-1 or 2 areas (see Figure SPM 7.1).

*** 'With mitigation' assumes that no SGD activities are permitted within sensitivity class 5 and within the Karoo Central Astronomy Advantage Area (KCAAA) (see Figure SPM 17.1).

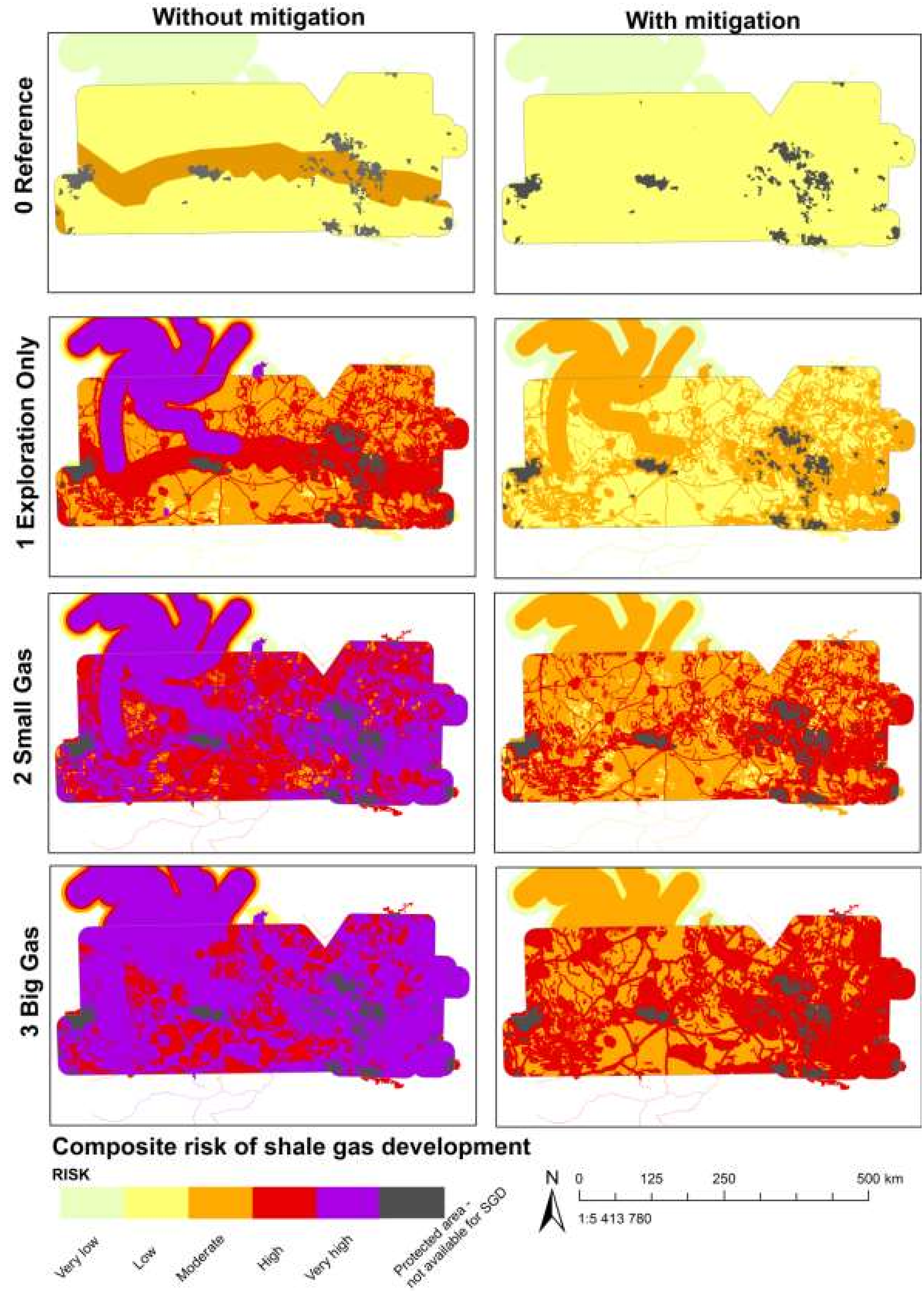


Figure SPM 19.1: Composite map of spatially explicit risk profiles within the study area, depicting the risk of SGD across four scenarios, without-and with mitigation.

The risk picture presents a mosaic of cumulative risk, evolving across the scenarios. Risks range from low to very high in the study area, with higher risk areas prevalent towards the eastern portion of the study area (Figure SPM 19.1). This may be attributed to more variable landscape features in the east which are characterised by a denser distribution of towns (Burns et al., 2016), more diverse habitats and a greater concentration of protected and sensitive areas (Holness et al., 2016), higher agricultural production potential (Oettlé et al., 2016) and an increased concentration of scenic resources and landscapes (Oberholzer et al., 2016).

Without mitigation, the risks associated with SGD from the Exploration Only to Big Gas scenarios increase incrementally from moderate-very high to high-very high. Effective implementation of mitigation and best practice principles may reduce the risk profile to low-moderate for Exploration Only, and overall moderate-high for the Small- and Big Gas scenarios.

There is major uncertainty regarding the nature and extent of a shale gas resource. Modern exploration, in its various forms, is the only way to increase the understanding of the resource and whether shale gas should be considered further in the country's energy planning and national discourse.

At the strategic-level of assessment, the risks associated with Exploration Only could be mitigated to low-moderate (considering both spatial and non-spatial risks). Good practice mitigation is reliant on the veracity of the future decision-making processes. These should be guided by evidence-based policies, robust regulatory frameworks and capacitated institutions in a manner that is ethical, responsible and transparent.

In the Exploration Only scenario, there are some moderate risks even after mitigation is applied. These include impacts to physical security and altered local social dynamics [§11.7]; occupational exposure to air pollutants on drilling sites [§3.2.5, §12.19]; EMI within sensitivity class 5 of the SKA [§17.3.5]; local road construction and regional pressure on road infrastructure [§18.3.2]; spatial and development planning and governance capacity [§18.3.2]. The impact of altered power dynamics is the sole impact assessed as high after mitigation within the Exploration Only scenario. [§11.6]

Application of the mitigation hierarchy will help to significantly reduce risks. The mitigation hierarchy prescribes avoidance as the most efficient manner to minimise impact exposure and hence to reduce the risk profile. Avoidance is most commonly applied within a spatial context to delimited areas that are unacceptable for development for one reason or another (sometimes many). Avoidance can also mean the prohibition of certain development activities if more suitable, less consequential alternatives exist.

Through effective project planning, many of sensitive features of the Central Karoo can be avoided. This includes high sensitivity water resources, EBIS-areas 1 and 2, high sensitivity agricultural land, heritage features, important tourism areas or routes, vulnerable people living in towns or rural communities, high sensitivity visual resources and the footprint of the SKA development phases.

All data, including spatial information, should be further tested and augmented during site-level assessments. This applies to specific development applications, where the nature, location and extent of SGD activities are clearly defined. Even though the most recent existing spatial data available were utilised for this strategic-level assessment, it must be recognised that information may be incomplete and/or contain inaccuracies. Most of the features mapped at the scale of this assessment will require additional project-level assessment processes to ground-truth sensitive features on-site.

The decision regarding SGD is not a binary *'yes'* or *'no'* question. There are a number of decisions which are made through multiple decision-making processes spanning all spheres of government and civil society (including the industry); potentially over an extended period time. Most of these decisions will be conditional rather than absolute decisions, meaning that certain activities may be permitted in one location and not another, or with a given set of requisite monitoring or management actions. This will depend on the specific nature of the activities and the location within which they are proposed.

Decisions regarding SGD should be considered in a 'step-wise' manner. If South Africa does choose to proceed with exploration, and an economically and technically suitable reserve is discovered in the future, due assessment of regional and cumulative impacts should inform decision-making prior to commencing with production of gas in the Central Karoo at a significant scale.

Baseline and ongoing data should repeatedly be collected and fed back into the evidentiary base to critically test decisions, the efficacy of management actions and scientific assumptions. As a starting point, South Africa is in the advantageous position of being able to accumulate a baseline dataset and start building or supporting the institutions capable of collecting, managing and analysing that data in a responsible manner.