Shale Gas Development in the Central Karoo: *A Scientific Assessment of the Positive and Negative Consequences*

SUMMARY FOR POLICY MAKERS (SPM)

CONTENTS

1. THE PRESENCE OF NATURAL GAS IN THE KAROO

1.1 The geology of the Karoo Basin

South Africa's geological Karoo Basin, which covers an area of 700 000 km^2, is known to contain natural gas. Within the assessment study area (Fig SPM 1.1), ~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]

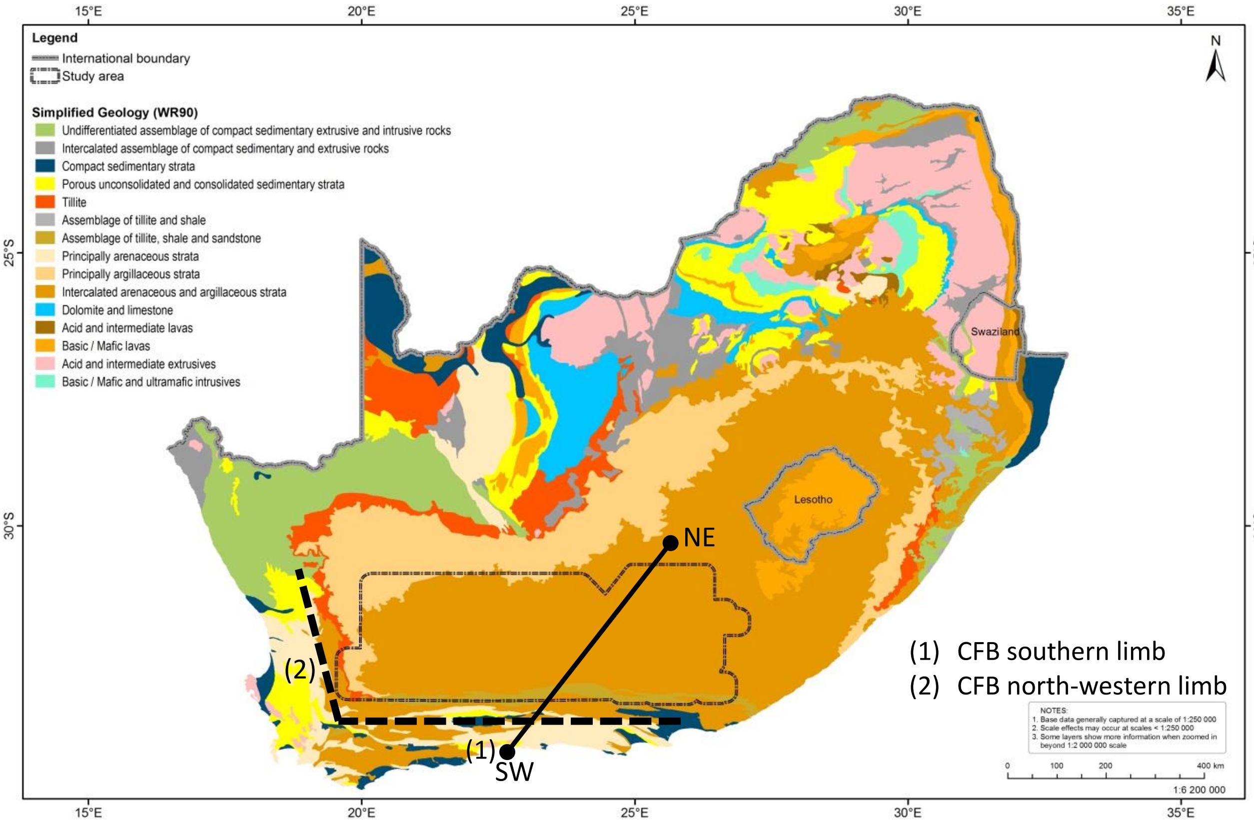


Figure SPM 1.1: Simplified geology of South Africa showing the large extent of the Karoo Basin (light brown and brown shaded area) deepening from the north-eastern interior to the south-central interior where it abuts against the southern limb of the Cape Fold Belt (CFB); section line SW-NE corresponds to the schematic profile in Fig SPM 1.3.

The 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 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" (Fig SPM 1.2). [§1.1]

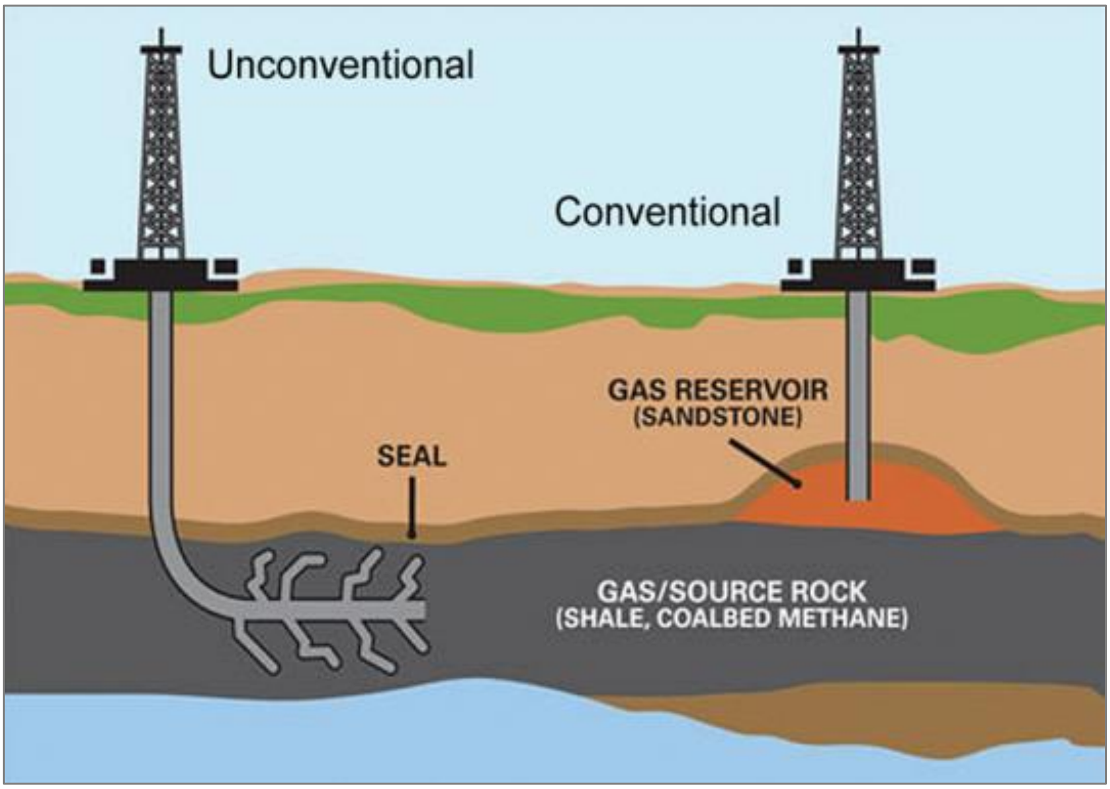


Figure SPM 1.2: In "conventional gas", a vertical hole is drilled into the reservoir and the gas flows out by itself. For unconventional shale gas, such as that which may occur in the karoo, the source rock lies very deep below the surface. The gas is tightly held and must be released by fracturing the rock around a wellbore extending horizontally into the gas-containing layer.

The total quantity of shale gas that may under the study area is uncertain, as is where exactly it may be concentrated. There may be none at all which can be economically extracted. Geological upheavals hundreds of millions of years ago, specifically the intrusion of dolerite (hot lava) and the pushing-up of the Cape Mountains are believed to have allowed much of the original gas to have escaped. Indications are that remaining gas is most likely concentrated in the area between the Cape Fold mountains to the south and the doleritic Nuweveldberge to the north, and at depths of greater than 2 km below the surface (Fig SPM 1.3). [§1.3.1]

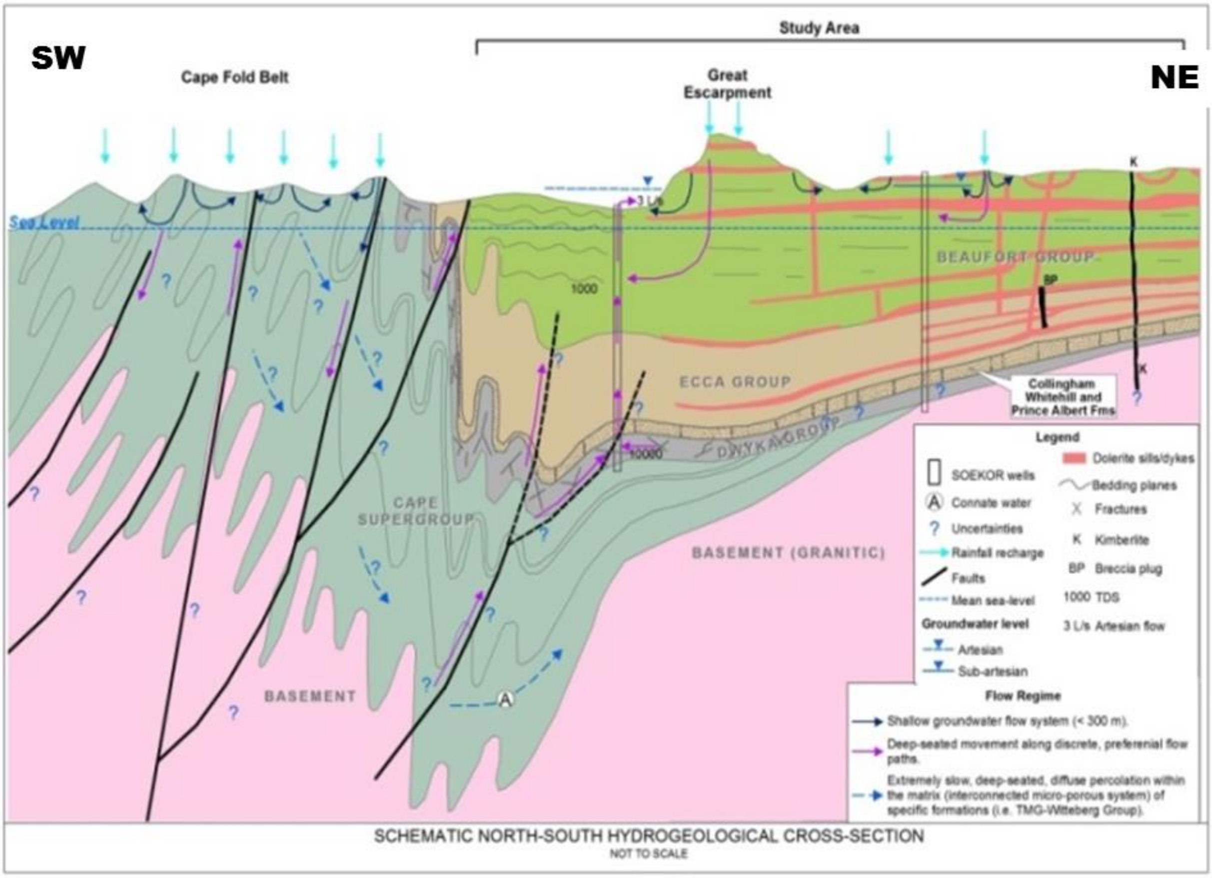


Figure SPM 1.3: A schematic diagram of the geology of the study area on a south west to north east transect between the Nuweveldberge and the Stormberge. The main layers which may contain gas are the Whitehill, Collingham and Prince Albert Formations, which occur at the base of the Ecca Group.

1.2 Stages of shale gas development

Shale gas development (SGD) entails a broad range of activities which occur over extended period of time in different "stages", at various intensities and with particular spatial footprints. This assessment covers all the material SGD activities, throughout their lifespan and for the period thereafter during which impacts can be anticipated (Fig SPM 1.4). It also addresses associated "upstream" and "downstream" activities. Upstream activities refer to aspects such as seismic surveys, site preparation, drilling deep vertical boreholes and the deviation of drilling to form horizontal wells that penetrate into deep targeted shale layers. They also include fracking of the shale layer and a host of other surface activities such as waste management, transportation of equipment, materials and personnel to and from areas of operations, and many others. Downstream use refers to how the produced gas is used, which may for instance be to generate electricity, or if found in sufficient volumes, for the manufacturing of petrochemicals. [§1.4.2]

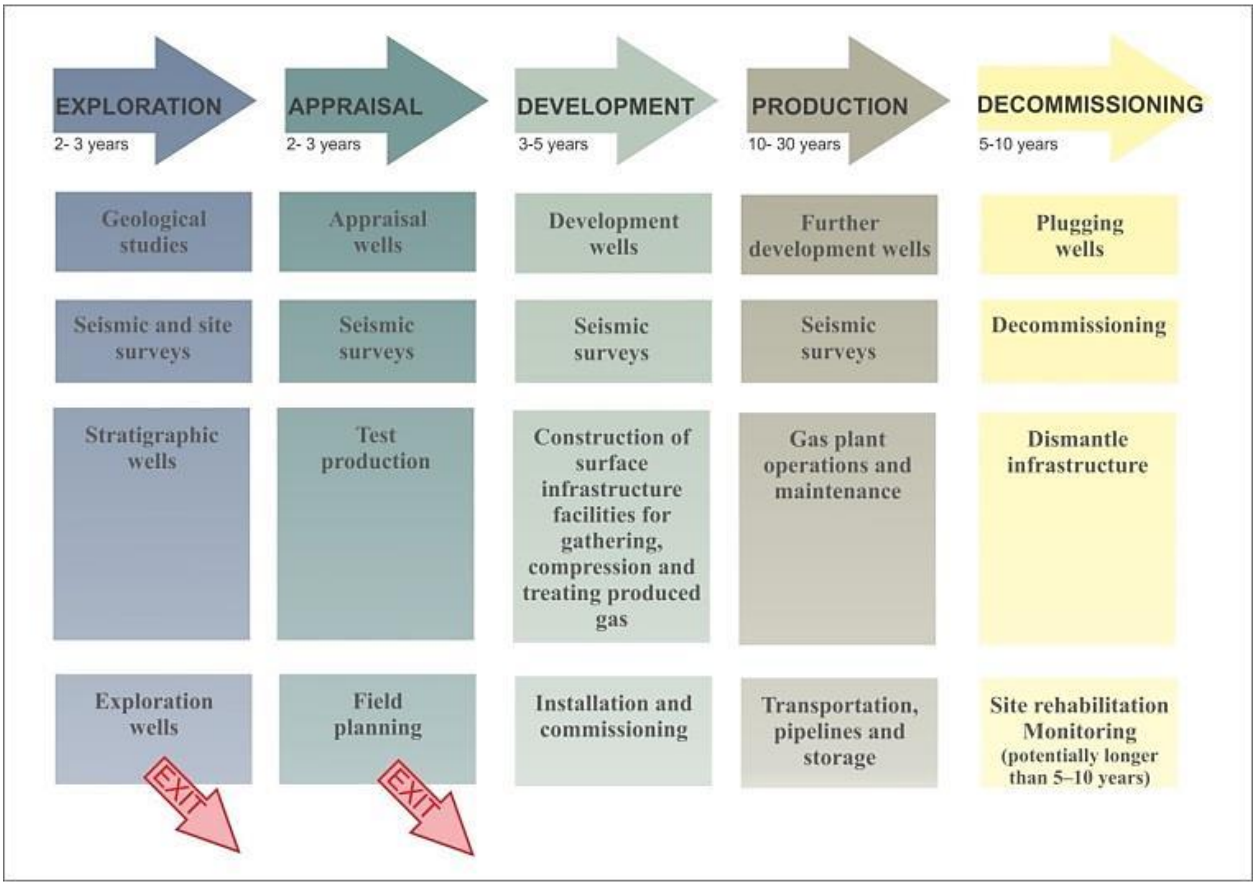


Figure SPM 1.4: Typical life cycle of a shale gas development project showing the stage, timeframes and nature of activities, as well as the exit points if gas is not found in sufficient volumes or at flow rates that make production economically unfeasible. Note that this timeline does not account for permitting and regulatory processes that would need to be undertaken in the South African context such as site specific Environmental Impact Assessments (EIA).

Exploration is the first stage of the shale gas development cycle. It is concentrated in the initial 2-3 years of the development cycle, but is undertaken throughout the life of the development to inform the location of additional drilling and production operations. It involves geological studies, seismic surveys and drilling of stratigraphic wells. Stratigraphic wells are vertical boreholes drilled to obtain geological core samples for analysis. Exploration wells also test for gas. The appraisal stage follows exploration, and for a single campaign typically lasts about 2-3 years. It involves the drilling of appraisal wells, which are vertical wells with horizontal sections to ascertain potential yields of shale gas within the target formation, following test fracking. Drilling, fracking and other equipment and materials and waste receiving facilities are contained on the well pad. An area of similar extent to the wellpads is developed for temporary accommodation of drilling crews in the region. If, during the exploration or appraisal phase, it is revealed that technically recoverable reserves cannot be economically exploited, decommissioning is implemented. [§1.4.1]

The production stage might last 10-30 years, with a concentration of activity in the first 3-5 years. It involves the ongoing development of production wells, gas plant operations and maintenance, and the transport of produced gas by pipeline to the downstream uses, either within the study area under the "Small Gas" scenario, or both within and outside the study area under the "Big Gas" scenario. Once the production phase reaches its conclusion, decommissioning extends over a period of 5-10 years. This involves the plugging of wells, dismantling of infrastructure and site rehabilitation. [§1.4.1]

During production, a typical shale gas wellfield could occupy an area of approximately 900km^2 containing 50-60 wellpads, each of which drills around 10-15 wellbores during its life. Because the horizontal part of the wellbore extends several kilometers from the vertical part, the wellpads in a production wellfield can be expected to be around 3-5 km apart. While the production wellbore is yielding gas, a new wellbore is drilled from the same wellpad and angled in a different direction into the gas-containing layer, to take over production when gas flow from the first bore declines. The well pads are connected by a network of unpaved roads and buried gas pipe lines. Each wellpad occupies about 2 ha, and contains a large drill rig along with buildings, storage tanks, pumps, trucks, and generators (Figures SPM 1.5 and 1.6). [§1.4.1]

Figure SPM 1.5: An example of the drill rig used for fracking, about 40m in height, located on a typical wellpad. Note the earth barrier around the wellpad, which is to contain spills.

Figure SPM 1.6: An example of a production wellpad with annotation of supporting infrastructure. In terms of current South African legislation, open water impoundments such as the one illustrated in this example would not be permitted.

During hydraulic fracturing, "fracking fluid" is pumped under high pressure into the gas-containing shale layers deep underground, via a horizontal well lined with a perforated tube. This causes tiny cracks to form in the shale, extending up to a few hundred meters 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 for several months, at a declining rate (Fig SPM 1. 7).

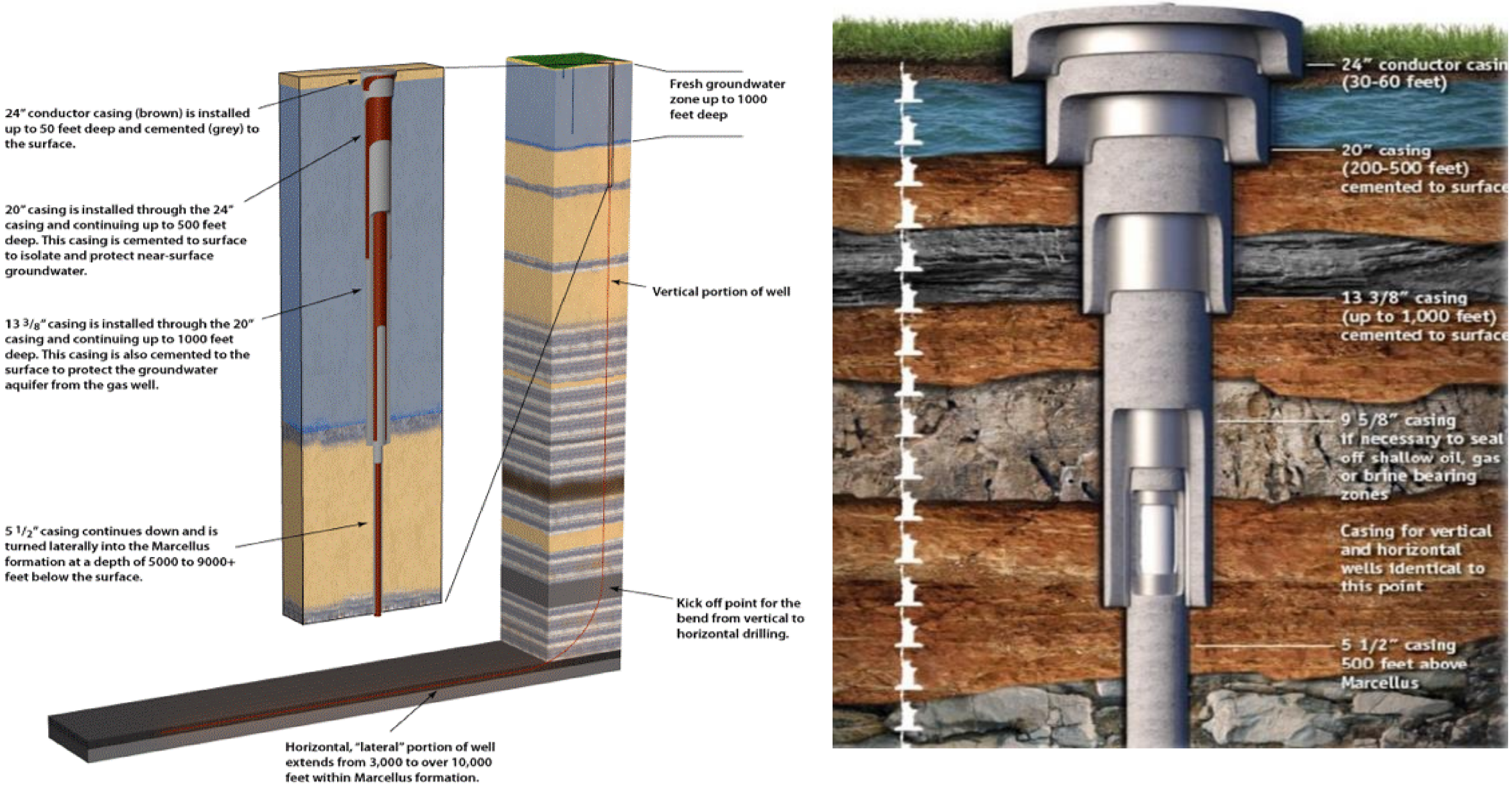


Figure SPM *1.7:* The vertical section of the wellbore between the target shale formation and the surface is sealed with a steel pipe, and in its upper sections where it passes through freshwater aquifers is grouted in place with a cement layer. The near-horizontal section of the wellbore, which is "fracked", runs along the shale gas-containing layer, for up to several kilometres. It is lined with a steel pipe, perforated with holes punched by an explosive charge.

The fracking fluid consists mostly of water but contains several additives, some of which are toxic. The several tens of millions of litres of "flowback" fluid, a mixture of fracking fluid and whatever liquid was in the shale, is stored temporarily in tanks on the surface and as much as possible is reused in the next fracking operation (SPM Box 1, Fig SPM 1.7). [§1.4.3.2.2.1]

SPM Box 1: The composition of hydraulic fracturing 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 considered so noxious or otherwise problematic that they are currently prohibited from use in South Africa in any hydraulic fracturing activities. These are listed in Addendum A to Chapter 1 of the Scientific Assessment.

Component	**%**	***Comments***
Water	95	Does not have to be freshwater
Sand	4	Props open the cracks. Very fine, so it can be a health hazard to wellpad workers if breathed in
Hydrochloric acid	1	Dangerous in concentrated form, such as while being transported
Polyacrylamide		Non-hazardous, however residual acrylimides are toxic & carcinogenic
Glutaraldehyde		Biocide (poison) used to eliminate corrosion-causing bacteria in water. Toxic and a strong irritant
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" and is mixed with 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 dangerous parts of the flowback are separated out, concentrated and sent to an off-site disposal site. The rest of the fluid, with additives topped up, is used for the next hydraulic fracturing operation. [§1.4.3.2.2.1]

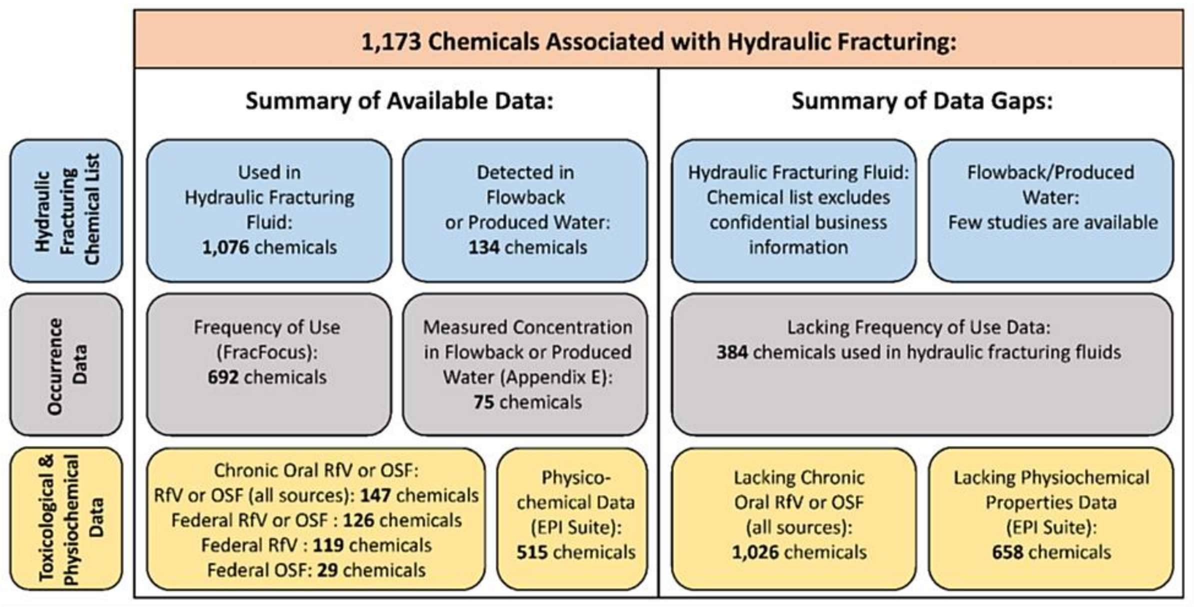


Figure SPM 1.7: A summary of existing information regarding chemicals used in hydraulic fracturing, highlighting gaps in knowledge. RfV refers to Reference Value, an estimation of an exposure, for a given duration, to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse effects over a lifetime. OSF means the oral cancer slope factor, a measure of carcinogenicity. [§1.4.3.2.2.1]

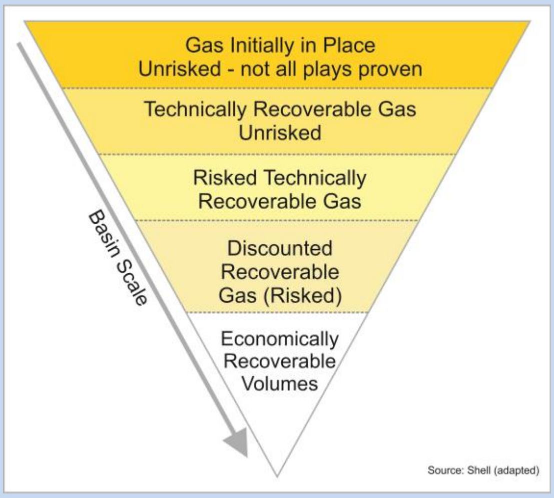
1.3 Shale gas development scenarios and activities

There is no history of exploitation for shale gas in South Africa, so this description of potential scenarios and related activities is necessarily hypothetical. A summary of the activity levels associated with the scenarios is given in Table SPM 1.1.

In Scenario 0 ("Reference Case"), there is no shale gas exploration, but the karoo changes nevertheless. Regional trends such as human migration, shifting economic activities and new development alternatives in the Central Karoo are realised, such as wind and solar energy and mining for other minerals. Climate change reduces the availability of water in the region. [§1.4.2]

In Scenario 1 ("Exploration Only"), exploration proceeds, but production does not. Exploration results indicate that production would not be economically viable and all sites are rehabilitated, drilled wells are plugged and monitoring of the abandoned wells is implemented. The national energy supply is supported by imported natural gas. [§1.4.3]

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



Technically recoverable resources represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas 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 technically recoverable gas reserve. Economically recoverable resources are those that can be profitably produced under current market conditions. The economic recoverability of oil and gas resources depends on three factors: the costs of drilling and completing wells, the amount of oil or natural gas produced from an average well over its lifetime, and the prices received for oil and gas production. [§1.3.2]

In Scenario 2 ("Small Gas"), about 5 Tcf of economically recoverable gas is developed. For comparison, the gasfield near Mossel bay will yield about 1 Tcf. Downstream development in the Small Gas scenario results in a 1 000 MW combined cycle gas turbine (CCGT) power station located less than 100 km from the production block. [§1.4.4]

In Scenario 3 ("Big Gas"), a relatively large shale gas discovery of 20 Tcf is developed. For comparison the offshore gasfields 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 plant located at the coast with a refining capacity of 65 000 barrels (bbl) per day. [§1.4.5]

It is not possible to be certain about what technically and economically extractable gas reserves may occur beneath the study area without much more detailed exploration, eventually including test fracking of the Karoo Basin shales. It is possible that no economically recoverable gas reserves exist at all in the study area; on the other hand, the economically recoverable reserves may be higher than the “big gas” scenario explored here. If so, the impacts will be quantitatively larger, but not qualitatively different. Typically the amount of gas which is *theoretically* present is many-fold higher than the amount which is eventually *actually* extracted at an affordable cost (SPM Box 2). The economic viability of SGD in the karoo will depend on the gas price at the time when the gas is produced (which may be many years from now) along with any cost-reducing advances in extraction technology that may have occurred by then. [§1.3.2]

Table SPM 1.1: A summary of the activities described in the three SGD scenarios in the detailed Tables §1.3; §1.4 and §1.5 of Chapter 1.

Activity	1. Exploration Only	2. Small Gas	3. Big Gas (assumes several wellfields)
Number of wellpads [2 ha each]	30	55	410
New roads (km) [unpaved, 5 m wide]	30	58	235
Total area of wellpads and roads (ha)	75	199	998
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 etc.	*85	**635	***4 185
Worker domestic waste (t/yr)	144	35	230
Worker sanitary waste (m^3/yr)	44 531	10 688	71 250

2. EFFECTS ON ENERGY PLANNING AND ENERGY SECURITY

The South African energy system is currently based mainly on coal, mined in South Africa, and imported oil and petroleum fuels, with a smaller contribution from nuclear, wind, solar PV and imported hydro-power. Natural gas is used only in small quantities. The largest energy supply subsector in South Africa is electrical power, about 90% of which is generated by burning coal. The heating sub-sector is small in South Africa. The transport sector uses liquid fuels, which are either

* For five exploration drilling campaigns, each with six exploration wells, total 30 wells over lifetime of Exploration Only activities.
** For 55 wellpads, each with 10 wells, total 550 wells over lifetime of Small Gas Development
*** For 410 wellpads, each with 10 wells, total 4 100 wells over lifetime of Big Gas Development

imported (in both crude and refined form) or domestically produced via coal-to-liquid (CTL) and to a lesser extent gas-to-liquid (GTL) processes. [§2.1.2]

Including more natural gas in South Africa's energy mix would make the energy system more efficient, cheaper and more reliable. Natural gas, regardless of its source, has a desirable set of qualities that coal and oil do not possess. Gas can be used in almost all subsectors (e.g. power generation, heat, transport, manufacture of chemicals); is easily transported once gas infrastructure is in place; is supported by a growing international market; is a more consistent fuel than coal (thus more flexible and easier to handle); is less CO_2 intensive when burnt than coal (if 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 capital- light and fuel-intensive, making it economically flexible. [§2.1.2]

Figure SPM 2.1: Combined Cycle Gas Turbines (CCGTs) in Algeria. Similar plants are planned as part of new CCGT capacity under the Integrated Resources Plan (IRP) 2010, regardless of whether exploitable shale gas is found in South Africa or not.

Gas is extremely versatile in the national energy mix because it can be used in many ways. If gas is appropriately priced and secure in supply, in addition to using gas to generate electrical power, compressed gas could be used for transportation, as input feedstock into GTL processes to produce liquid transportation fuels, for fertiliser production, for industrial heat, for space heating and for residential cooking and hot water. [§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. Natural gas can be sourced internationally via pipeline from neighbouring countries and/or as imported liquified natural gas (LNG). Domestic sources include the possibility of offshore conventional gas fields in South African waters, or unconventional onshore sources such as shale gas or coal bed methane (CBM). South Africa will likely initially promote LNG imports to stimulate a large '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 will be supplemented with increasing volumes of gas imported by pipeline, for instance from Mozambique. [§2.1]

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. The NDP has clear objectives and actions to support increased natural gas use in the energy mix, irrespective of whether that gas is sourced domestically from SGD, or imported. 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) links the plans for the various energy sectors 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 demand and supply into South Africa's diversified future energy mix. All these plans are owned, developed and implemented by the Department of Energy (DoE), in consultation with other government entities and non-governmental stakeholders. [§2.1.3]

The availability of high volumes of shale gas at a competitive price would alter South African energy plans. A likely outcome would be less use of coal. With high volumes of shale gas it is likely that gas will be priced at relatively low levels. 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]

High volumes of shale gas would enable the integration of more renewables into the mix and reduce the portfolio costs of power generation. Large volumes 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. Thus a portfolio containing all three is cheaper to build and operate than any one alone, for now and the foreseeable future. As such, shale gas finds would not change the selected planning scenario for the electricity sector, which already calls for more natural gas plus renewables, but would likely make this scenario cheaper and cleaner. [§2.2.2]

High volumes of shale gas in South Africa 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 a bit more complicated but would help it to be more integrated and resilient. Natural gas would be the "pressure valve" between sectors, allowing for adjustments to changing planning assumptions between sectors. [§2.2.2]

The risk to South African energy plans of not finding shale gas is small. Gas demand could be supplied from imports if not viable domestically. The IRP considers gas on the basis of its cost, not primarily on the basis of where it originates from. The main shale gas related risk to energy planning occurs if gas infrastructure investment decisions are taken in anticipation of shale gas finds, which subsequently do not materialize. This could result in an energy infrastructure that is not optimal for the energy future which actually occurs. The risk is small because many of the planning decisions involving gas are "no-regret" options. The capital expenditures needed (gas-fired power stations, gas-fired boilers, gas cooking/heating, etc.) are small relative to alternative new-build options, such as large coal-fired stations, and therefore do not have a major effect on the overall costs of the energy system. There is also a very low risk related to locking the country into energy infrastructure that is not compatible with the optimal energy future of the country (as a result of more than sufficient infrastructure planning). [§2.2.2, §2.3.1]

Gas can help deliver modern energy to historically disadvantaged populations. Communities in the immediate area of SGD would benefit from the local availability of 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

SGD without mitigation would be associated with a high risk of occupational exposure to air pollutants. SGD activities will lead to occupational health risks at the well site due to emissions of diesel exhaust, NO_2, PM, VOCs, silica, and H_2S (if present in the 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 local communities, the risk of exposure to air pollution is driven by the increase in ambient Particulate Matter (PM) concentrations, which already exceeds the National Ambient Air Quality Standards (NAAQS) in the karoo, 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 large emission increases, ambient concentrations of pollutants other than PM should remain within NAAQS. With mitigation involving available technologies and best practice, local community exposure to NO_x, PM and VOCs can be reduced to low risk. [§3.2.4.3]

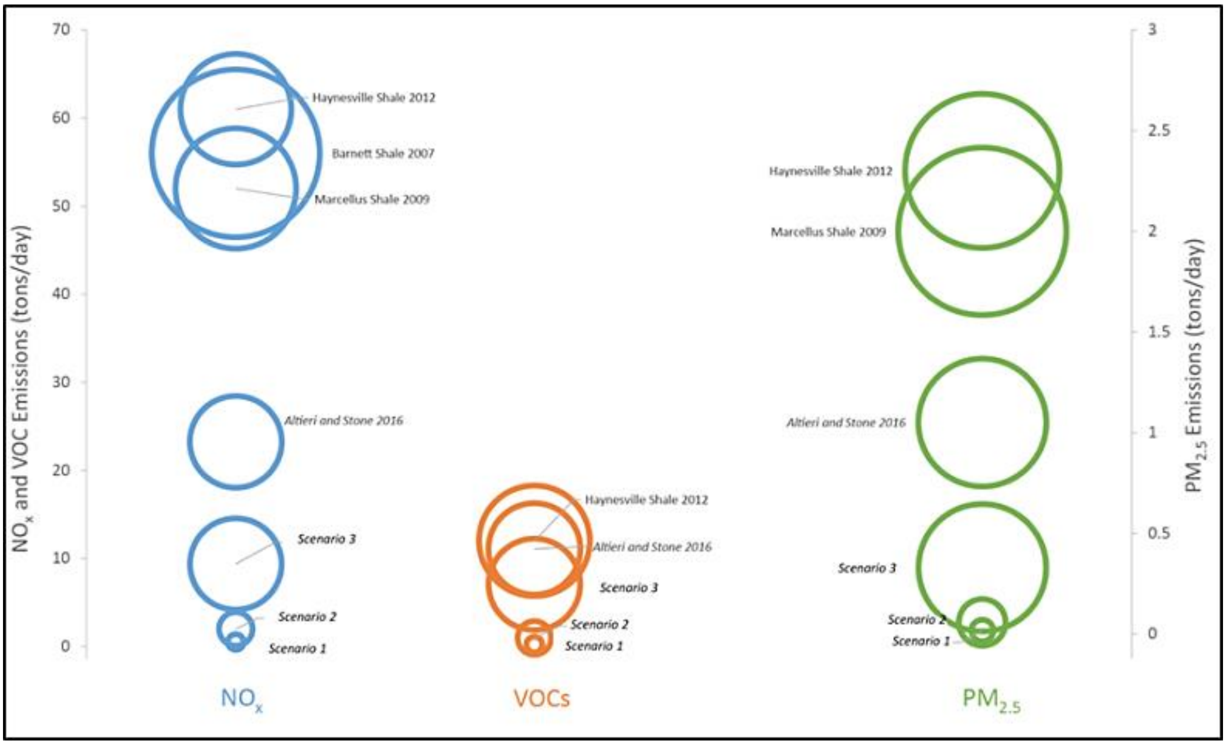


Figure SPM 3.1: Air pollutant emissions estimated for SGD in the Karoo, and main shale plays in USA (Marcellus, Barnett and Hayeville, and summary reports by Abieri and Stone 2016). The "bottom up" South African estimates are much below the "top-down" actual USA observations for three reasons: some states in the USA have weak regulation regimes for gas-related pollutants; the newer technology which would be applied in South Africa is anticipated to be less polluting; and "bottom up" estimates based on industry-supplies information sources are typically optimistic about the level of emission control which is actually achieved.

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 site, and the transport of waste and water from the well site to regional waste centres. Routing trucks away from places where people live 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 indoors with inadequate venting. [§3.2.4]

There is insufficient information on air quality and GHG emissions in the Karoo to form a reliable baseline against which to measure the impacts of SGD. There are no air quality monitoring stations within the study site, and only one near it, critically limiting information on air quality prior to shale gas development. [§3.3.2.1]

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 SA); or whether instead it displaces low-carbon energy sources; or whether gas is used *in addition* to coal. Shale gas used in place of coal for electricity generation provides an opportunity to reduce GHG 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. (Fig SPM 3.2). [§3.3.4.3]

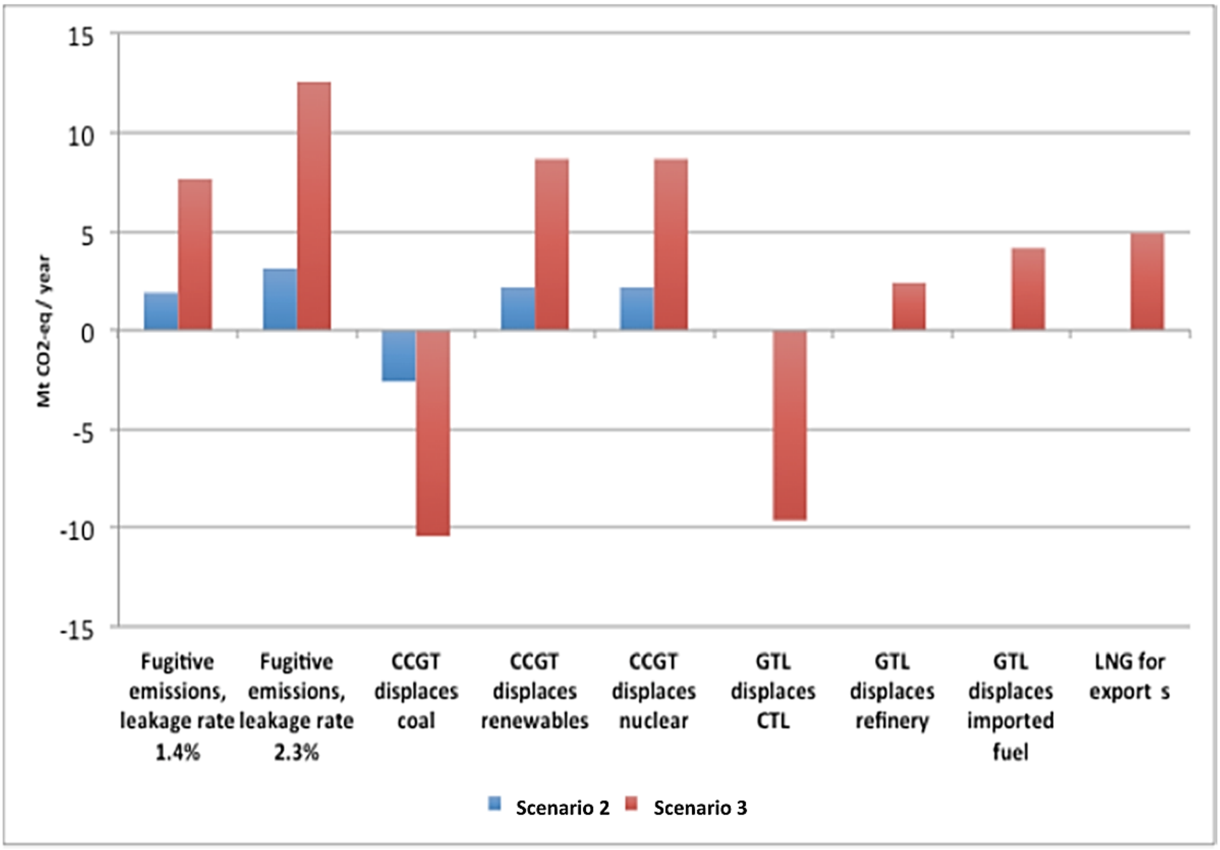


Figure SPM 3.2: The net change in national greenhouse gas emissions which would result from SGD under various assumptions. The total South African emissions in 2010 were in the region of 400 Mt CO_{2eq}. Note that the outcome of SGD implementation could be either a small increase or a small decrease, depending on what is displaces and what fraction of the methane leaks to the atmosphere uncombusted.

For the Big Gas scenario with inadequate control of gas leaks, the risk that fugitive methane emissions will cause the GHG benefits to be eroded or reversed is assessed as high. Methane has a greenhouse warming potential twenty to thirty times higher than carbon dioxide, so relatively small leaks (a few percent) can offset the benefit that accrues from the higher energy yield per unit carbon dioxide emitted when gas is used in the place of coal. This risk could be reduced to moderate with mitigation involving good practice and available control technologies [§3.3.4.1]

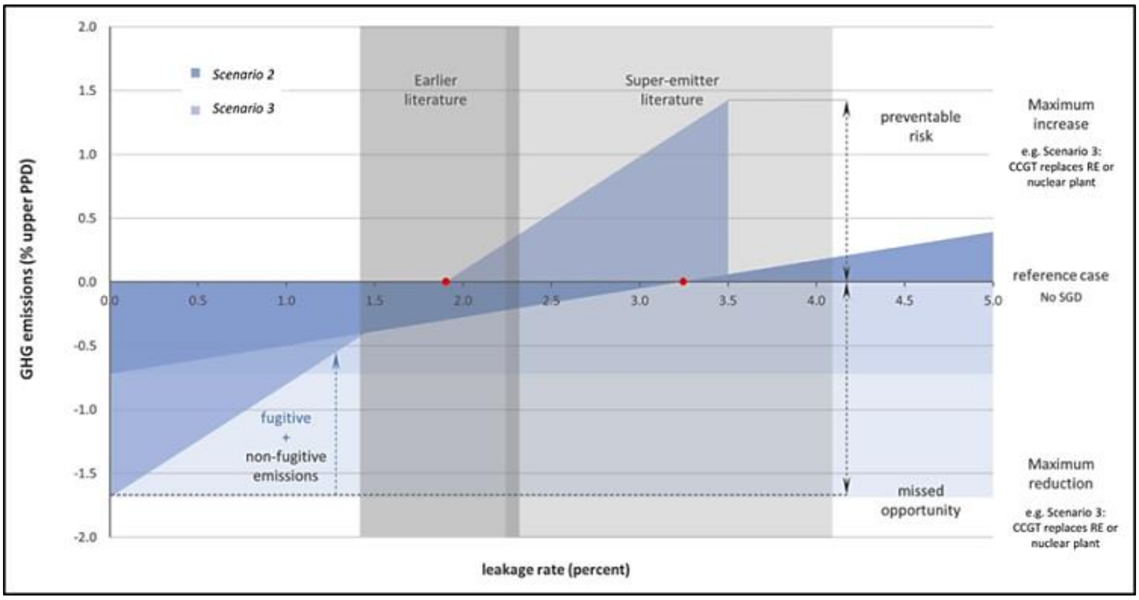


Figure SPM 3.3: Increasing fractions of methane gas accidentally ("fugitive") leaking to the atmosphere would cause the greenhouse gas emission benefits of using shale gas to be progressively lost. The GHG no-benefit threshold occurs at 1.9% leakage under the Small Gas scenario, and 3.2% under the Big Gas scenario. The estimates of leakage worldwide was 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%.

4. EARTHQUAKES

SGD by hydraulic fracturing increases the likelihood of small earth tremors near the well bores. Only a few 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 hydraulic fracturing. The possibility that hydraulic fracturing will trigger damaging earthquakes (i.e. of magnitude 5 or greater) through interaction with natural faults cannot be excluded, but the risk is assessed as low because the study area very rarely experiences tremors and quakes (Fig SPM 4.1). Damaging earthquakes caused by SGD are almost exclusively associated with the disposal of large volumes of waste water into geological formations (which is forbidding in South African legislation); not with the development of shale gas resources using hydraulic fracturing. [§4.1.1, §4.1.2]

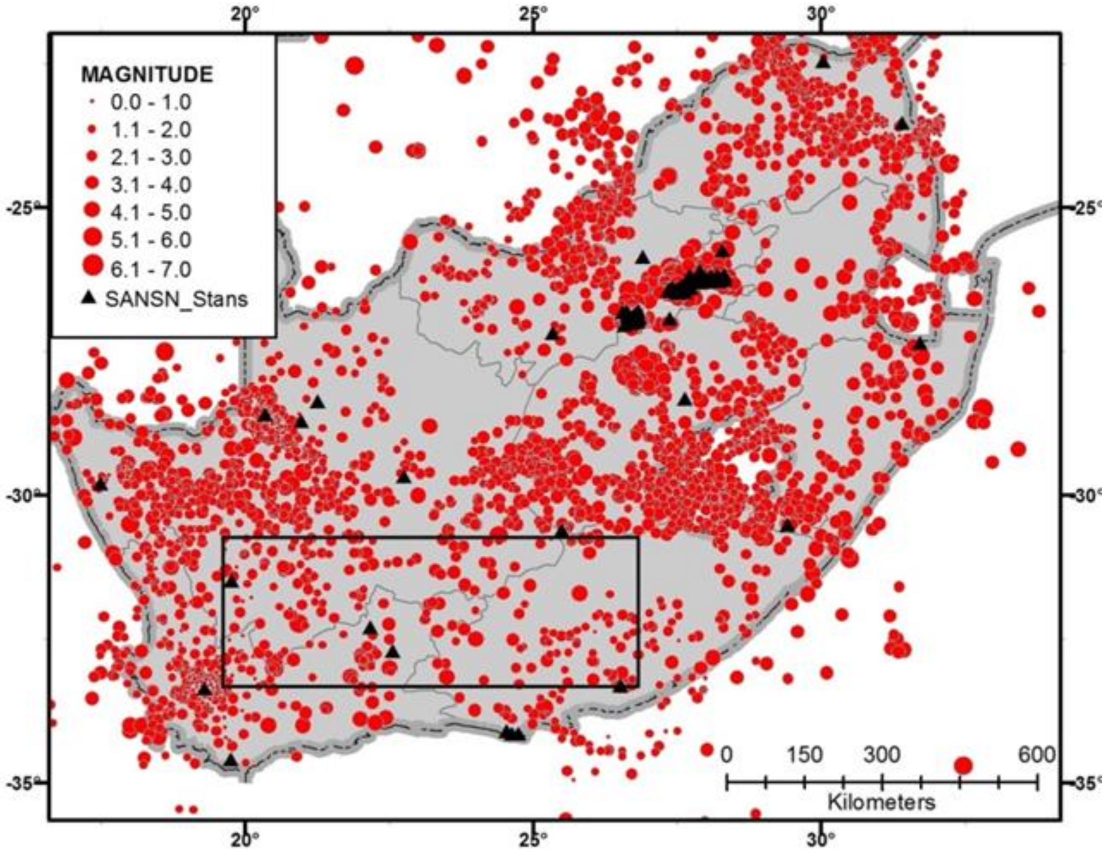


Figure SPM 4.1: The locations of recorded seismic events in South Africa. The black triangles are locations of seismic monitoring stations; the black rectangle is the study area. The study area is relatively seismically quiet.

The elements of the study area most vulnerable to earthquakes are heritage buildings made of unbaked clay bricks, and poorly-constructed low-cost housing. These structures can be damaged by earthquakes above magnitude 5 and severely damaged by earthquakes above magnitude 6. Their collapse could cause human injury or death. [§4.1.2]

Locating sites of hydraulic fracturing a safe distance from population centres and concentrations of heritage buildings reduces the risk of earthquakes resulting from SGD to very low. The intensity of shaking decreases with distance from the epicentre of the earthquake. At a distance of 20 km the likelihood of damage is reduced to close to the background risk. Current regulations prohibit the disposal of wastes by injecting them into deep wells. This practice has been the main contributor to the increased number of earth tremors large enough to cause damage in other parts of the world. [§4.3.2]

A denser network of seismographs is needed in the region prior to the commencement of hydraulic fracturing. The seismograph would need to function throughout operations and after closure until seismicity decays near to background levels. The instruments should be of the type used by Council for Geoscience, and located at sufficient density to enable the hypocentre of the tremor to be associated unequivocally with a particular well. A survey of potentially at-risk structures, including buildings and bridges within 20 km of proposed fracking operations must be undertaken, and where possible vulnerable structures should be strengthened. [§4.4]

5. SURFACE AND UNDERGROUND WATER RESOURCES

Water availability in the study area is already severely constrained, and thus the capacity to supply water for SGD from existing local sources is very limited. Surface water availability is generally low. Most streams are non-perennial, episodic and ephemeral, with very high inter-annual variability. The surface water resources in the study area are already stressed (and in many areas over-allocated) to meet the demand of existing users. Central karoo landowners are mainly reliant on groundwater resources for domestic and stock water supplies. Groundwater recharge is typically low and sporadic. The development of groundwater resources to meet shortfalls in surface supplies is increasing, particularly during drought years, and in many areas already supplies 100% of the demand. The availability of potable groundwater resources in the study area to meet the additional demand of development plans not involving SGD – such as irrigated agriculture, tourism or mining - is seriously constrained. [§5.2.2, §5.2.3, §5.2.4, §5.3]

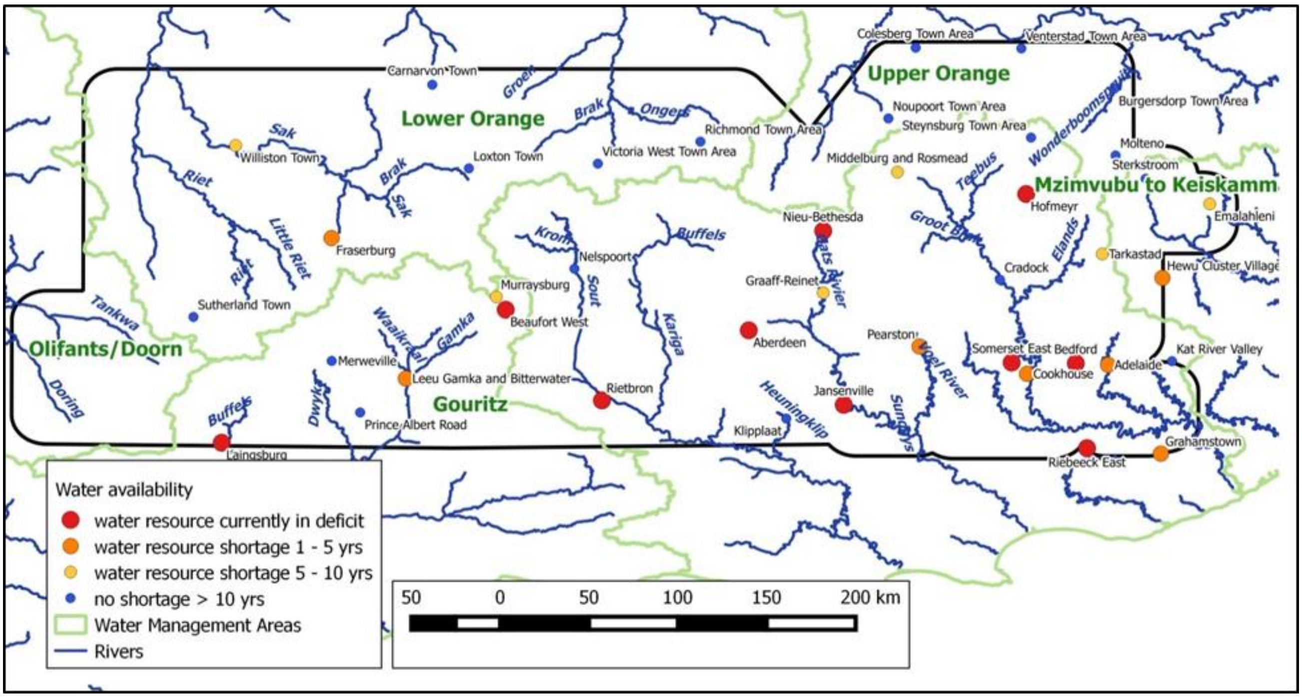


Figure SPM 5.1: Water availability and predicted shortages for each town or settlement in the study area; each point represents a municipal supply scheme which, depending on the municipality includes domestic, industrial and agricultural use

There is potential to develop non-potable (brackish or brack) groundwater resources for purposes of hydraulic fracturing, at a limited scale. This, however, will need to take into account potential impacts associated with the transport and storage of this water, as well as potential impacts due to water wellfield development. [§ 5.3.1]

Surface spills on-site and along transport networks are the most likely source of water resource contamination resulting from SGD. The risk 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 if best practice techniques are observed. On the other hand, impacts arising from spills of contaminated fluids on the wellpad and accidental spillages of noxious or toxic material during transport are near-inevitable under both the Small Gas and Big Gas scenarios, given the volumes involved, the duration of the activity, and its distributed nature. Although spills are on average expected to have localized and short-term impacts, their actual location in the landscape will inform the magnitude of their impact, which could be locally high. If the spill enters a river system during flood events, downstream impacts can occur (Fig SPM 5.2). [§5.5.1]

Cumulative impacts from other activities will compound water scarcity and quality concerns. The study area is also the focus of other potential development such as mining, irrigation schemes and growing human settlements. SGD-related activities such as hydraulic fracturing, road building and workforce accommodation will place an additional demand on water resources and present a risk of contamination. Non-SGD activities such as uranium exploration and mining will compound this demand and pose additional contamination risks. The impacts on water quantity and quality are cumulative. [§5.5.1]

Post-SGD legacy impacts on water resources will occur. Impacts following the completion of SGD (e.g. from failed well linings or capping structures on spent production wells) are a cumulative and inevitable legacy issue far into the future. Where these impacts are traceable (e.g. from monitoring data), containment is feasible following site-specific assessments to identify the most appropriate mitigation measures and monitoring to establish their success. However, since they may only arise long after SGD has ceased, there are concerns over the likelihood of timely detection of contamination and the availability of funding for remediation. [§5.5.1.4]

Improved water resources monitoring before, during and after SGD is an imperative. SGD must not proceed before a comprehensive set of baseline water resource data for the study area has been established. This must include surface 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. Ongoing water resource quality monitoring including general and SGD-specific determinants is essential during and after SGD. [§5.8]

There is currently a deficit of laboratories in South Africa to undertake the necessary analysis for water chemistry monitoring in relation to SGD. Although most accredited local (South African) laboratories are equipped to carry out routine water analyses (e.g. major cations and anions), none are presently capable of analysing for 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; baseline establishment in the immediate term may require the use of internationally-accredited laboratories. [§5.8.2]

A comprehensive determination of the Reserve (for groundwater, surface water and wetlands) for basic human needs and ecological requirements must be carried out before SGD occurs. The authority (Department of Water and Sanitation) responsible for Reserve determinations will not issue water use licences without a comprehensive Reserve determination having been completed. [§5.4.3.1]

Current lack of infrastructure and institutional capacity for water management is a constraint in the karoo. Insufficient institutional and human resource capacity is a severe constraint to the implementation and execution of a robust and effective water resource monitoring and management programme for SGD. This constraint will apply to regulatory authorities, who often lack the necessary skills and the will to exert enforcement, and less so to the SGD industry, which it is expected will mobilize the necessary resources to meet regulatory requirements in this regard. This constraint is particularly relevant to independent monitoring and evaluation activities directed at ensuring compliance of the SGD industry with the regulatory requirements. The likelihood of environmental non-compliance is increased by poorly capacitated regulators. [§5.2.2.7]

SGD provides a learning opportunity that will improve understanding of local water resources. The activities associated with SGD create a significant opportunity to 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 will be realised whether SGD advances to production capacity or not, as the potential will be revealed mainly during the exploration phase. [§ 5.7.1]

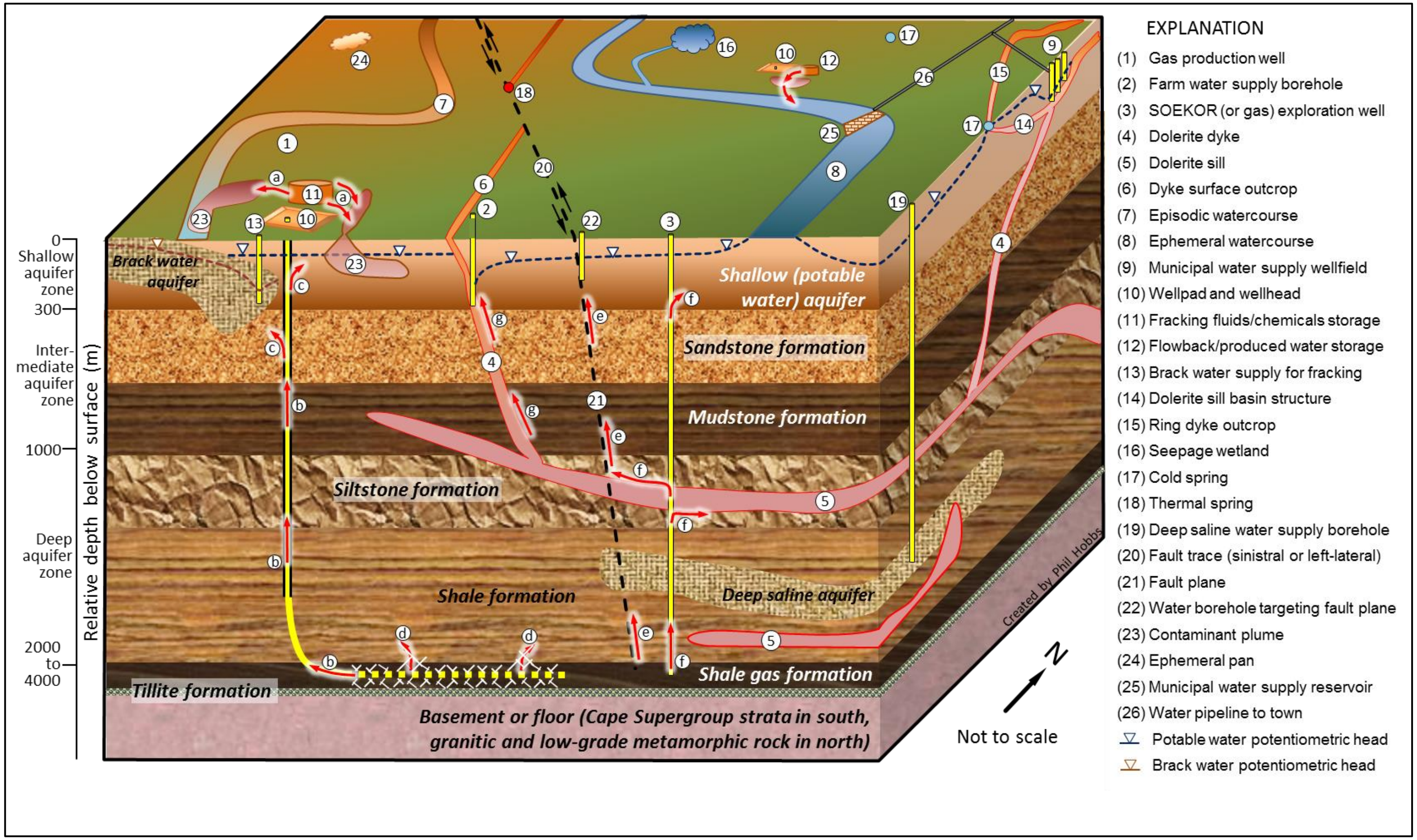


Figure SPM 5.2: The features associated with the surface water and groundwater environments as these relate to shale gas development activities. The possible contaminant pathways (red arrows) and plumes (feature 23) are conceptual and exaggerated for explanatory purposes. The thickness and types of rock layers is similarly for illustrative purposes. 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) escape/leakage via old (possibly uncased) oil and gas exploration wells, and (g) preferential migration along dyke/sill contact zones.

6. WASTE PLANNING AND MANAGEMENT

SGD will generate substantial volumes and new types of waste in the study area. These include liquid wastes such as flowback fluids, 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 water and construction waste. [Tables §1.3; §1.4 and §1.5 of Chapter 1]

The existing legislated waste management provisions are adequate to reduce the waste-related risks of SGD to low, if rigorously enforced. Following the 2015 Petroleum Exploration and Development Regulations is mandatory and should not be relaxed by any future amendments. They include impermeable site underlay systems, site drainage arrangements, above-ground tanked storage of wastewater and drilling muds, disclosure of additives and chemicals in muds and fluids via safety data sheet information, testing of samples of flow-back or produced water as prior to removal from the site, re-use of fracturing fluids to reduce competition with fresh water use, compliance to waste disposal regulations other than those specifically listed under Petroleum Exploration and Development, prohibition of underground disposal, prohibition of discharge of untreated hydraulic fracturing fluids and flow-back and produced water into surface water courses, categorization of solid waste generated during operations and its appropriate disposal at a licensed landfill site or treatment facility. Recovery of drilling muds and fracking fluids will require a waste management license in terms of the Waste Act (2008). [§6.3]

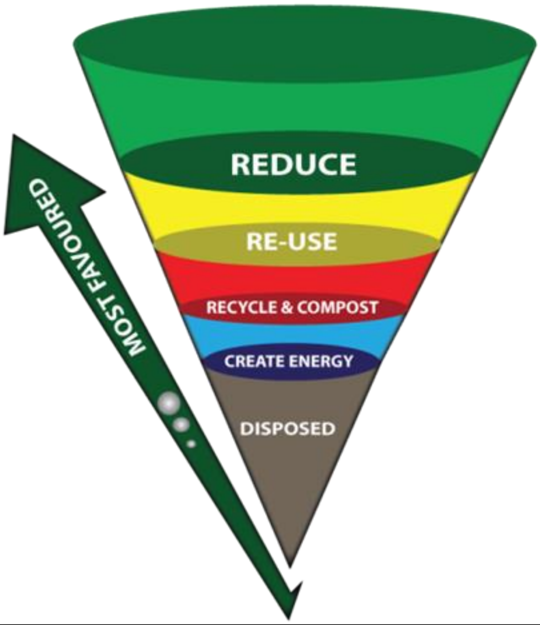


Figure SPM 6.1: The Waste Management Hierarchy, favoring the options for reducing waste wherever possible, re-using all types of water related to SGD, recycling of materials such as flowback fluids and then disposal as a final step if none of the previous options prove feasible.

Currently, no hazardous waste sites are licensed for the disposal in the study area. This means that any hazardous waste would need to be transported and disposed of outside the study area. Mining-related waste, including that from SGD, is currently classified as hazardous, thus requiring specialized disposal sites and procedures. If this were to change with respect to SGD, wastes could legally be disposed in municipal landfills, which are currently completely inadequate for this purpose and could have health impacts if people are exposed to it. Technologies employed at municipal landfills are inappropriate to deal with the quality of the waste water generated by SGD and the design capacities of these facilities are also insufficient to deal with additional volumes. Leach management and treatment is a pre-requisite for disposal of shale waste to landfill due to the presence of a range of toxic chemical additives and potential radioactivity and salinity in flowback water (leachable Naturally Occurring Radioactive Materials (NORMS). 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 implementation level and will therefore have to be strengthened before SGD is approved. [§6.2, §6.4, §6.4.3]

If waste from SGD is managed in an integrated way, in line with the waste management hierarchy and the principles for integrated waste management in South Africa, the waste-related risks are low. The emphasis here is to minimise waste arising, promote the use of non-hazardous chemicals, reuse and recycling and minimise the impact of waste on water, the environment and communities. [§6.1]

7. BIODIVERSITY AND ECOLOGICAL IMPACTS

The study area includes relatively high levels of biodiversity, including highly 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]

Areas identified in this assessment as being of very high ecological importance and sensitivity are irreplaceable if substantively damaged. Widespread impacts in these areas would undermine the ecological integrity of the study area (and more broadly, the Karoo). Any activities, including but not restricted to SGD, in these areas are assessed as very high risk. The very high and high ecological importance and sensitivity areas make up an estimated 55 % of the study area. Only 5 % of the study area is formally protected in National or Provincial reserves. The primary mitigation for SGD with respect to biodiversity is securing the areas of very high and high ecological importance and sensitivity. This effectively frees up medium-low and low areas for development. Strategic mitigation at the landscape level, involving avoidance and securing of areas of very high and high importance and sensitivity is essential, as the impacts of SGD cannot be effectively mitigated on site or at the operational level. The areas of very high and high ecological importance need to be retained in a near-natural state and secured through appropriate zoning or legal mechanisms that limit habitat loss or degradation in these areas. This may involve formal protected area declaration (including through biodiversity stewardship agreements), but can include other types of stewardship, protection through other legal means, protection under Section 49 of the MPRDA and appropriate designation in land use schemes. This may lend itself to a fast-tracked, integrated protected area expansion strategy. (Fig SPM 7.1) [§7.3]

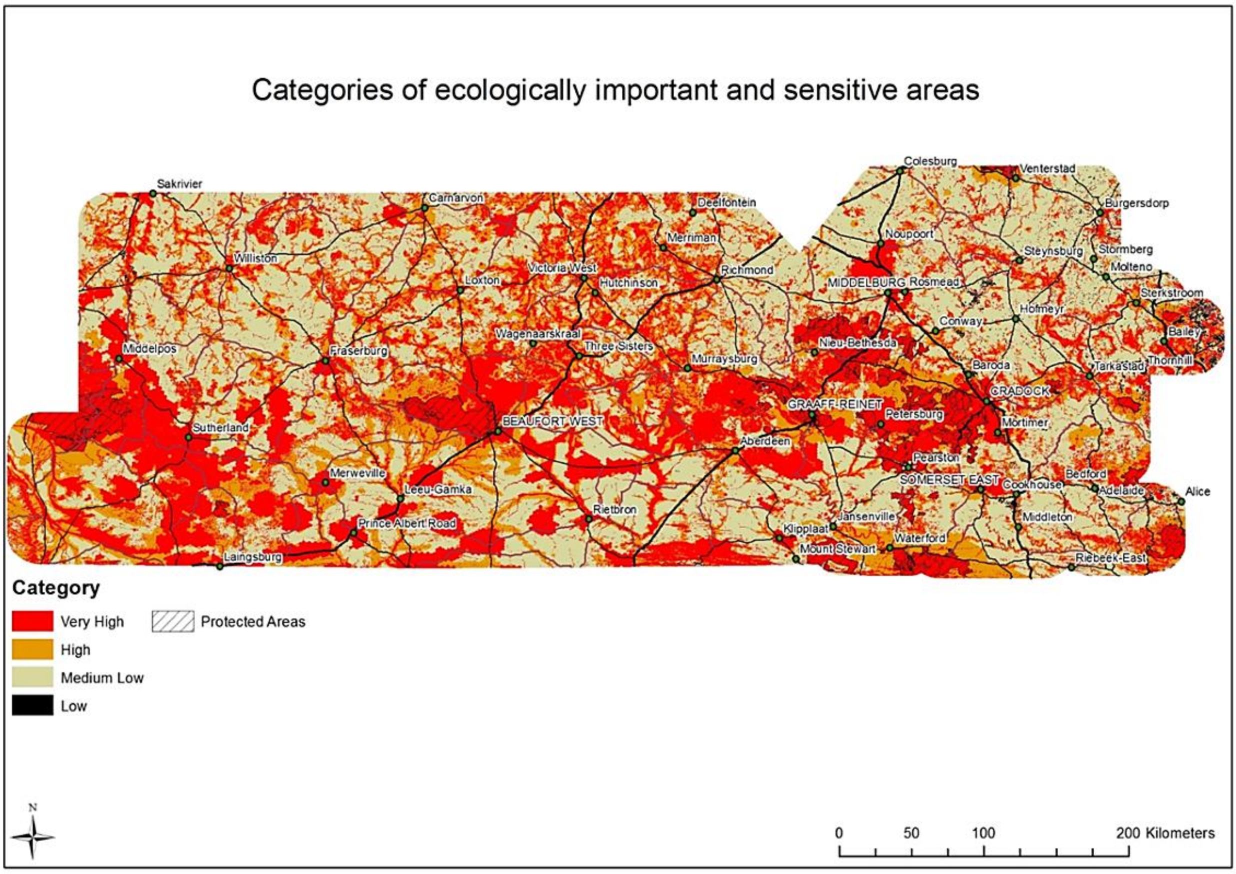


Figure SPM *7.1*: The ecologically important and sensitive areas within the study area

The Karoo is an arid ecosystem characterised by ecological processes that operate over extensive areas. In addition, the Karoo is sensitive to disturbance, and disturbance has long-term impacts. Recovery in disturbed areas is generally not spontaneous and active rehabilitation is often met with poor success. [§7.1.3]

Mitigation of ecological and biodiversity impacts must take place primarily at the landscape scale rather than solely on the physically-disturbed footprint. 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 disturbance can extend for hundreds of metres or kilometres from the source. 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 dense network of linear structures could undermine the biodiversity integrity of the study area. Impacts on species and ecological processes are likely to have cascading effects on other species and processes. [§7.2.1, §7.2.2, §7.3.4]

Where activities in areas of high ecological importance and sensitivity are unavoidable, their impact should be minimised by strenuous mitigation efforts. Only as a last resort should they be offset by securing alternate sites for the representation of biodiversity and maintenance of ecological processes, and in this case appropriate national and provincial offset guidelines and methodologies should be applied to ensure no net loss. [§7.3.4]

Environmental compliance is still required in areas of medium-low and low ecological importance and sensitivity. This includes specialist-led assessment of local sensitivities and identification of appropriate mitigation. This is necessary to ground-truth desktop assessments and minimise impacts. [§7.4]

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. [§7.2.2]

8. IMPACTS ON AGRICULTURE

The biggest potential threat of SGD to agricultural production in the study area relates to the use and availability of water resources. In the dryer central and western parts of the study area, farming communities rely exclusively on boreholes for the provisioning of 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 through the SGD process for agricultural production purposes, should it be either of an acceptable quality or amenable to purification. [§8.5.1, §8.7, §8.8.1]

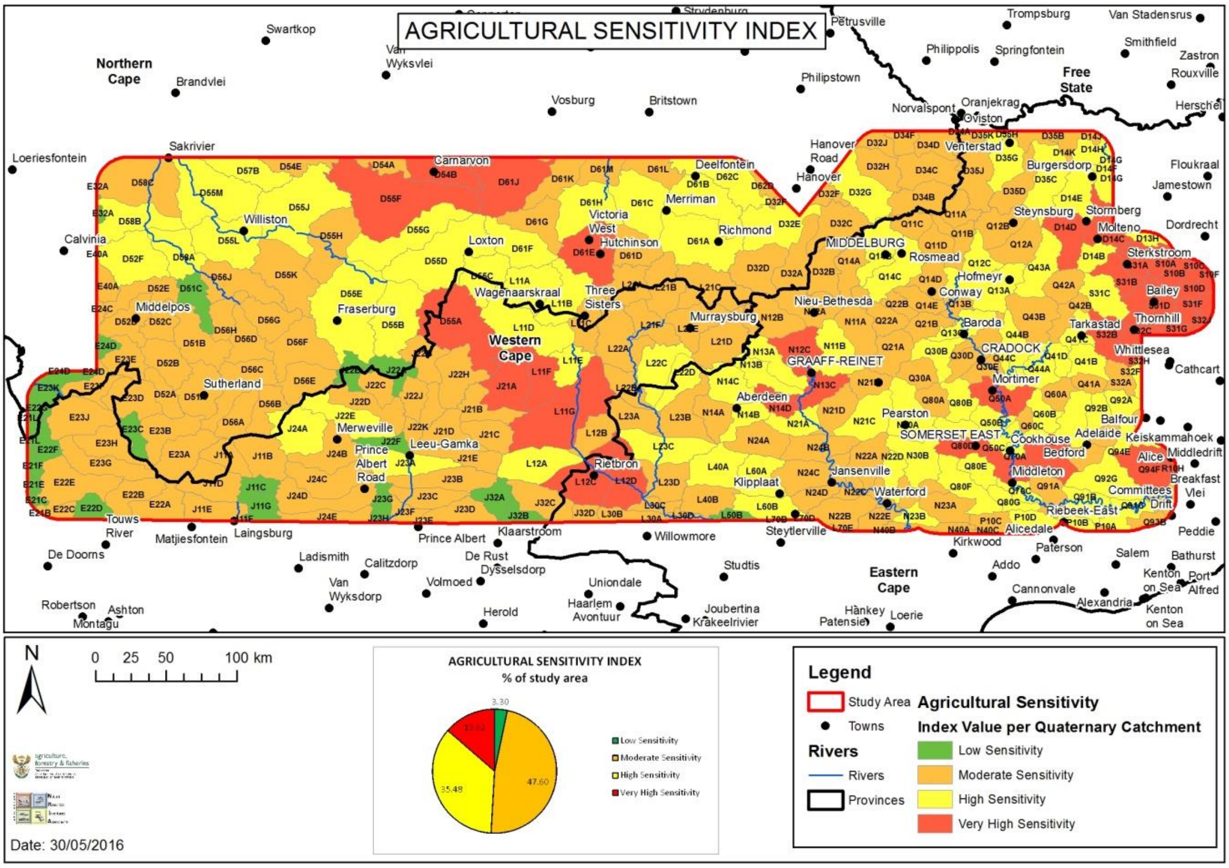


Figure SPM 8.1: An index of agricultural sensitivity in the study area

SGD will not have a significant impact on agricultural productivity in the long term if the threat to ground water resources is adequately addressed. The central and western parts of the study area are areas of low potential plant productivity in a national context, yet have made a relatively constant contribution to regional Gross Domestic Product (GDP), and sustained local livelihoods. The area offers limited options and opportunities for intensive farming operations and is thus typified by large, farms, low inputs per unit area and low levels of population. There is a trend amongst land users to move towards alternative sources of land-based incomes such as eco-tourism and hunting. [§ 8.5]

Any intervention that destroys 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 these vulnerable land-based resources. Fragmentation of the landscape to accommodate SGD must be carefully planned to minimize the negative impacts on the viability of agricultural enterprises. Some land may be taken out of production (leased or purchased) while SGD is underway which would potentially have a positive impact on the incomes of agricultural land users. It would only 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. [§8.2.1]

Sufficient policy, legislation and regulation exist to protect the natural agricultural resources. The enforcement of these instruments remains a major stumbling block to sustainable resource use and prevention of the degradation of agricultural resources. Current legislative and policy instruments include the Conservation of Agricultural Resources Act (CARA), Act 70 of 1970 (Subdivision of Agricultural Land), the Spatial Planning and Land Use Management Act, and the National Policy on Food and Nutrition Security. However, the institutional capacity, skills and knowledge to implement or enforce these measures are limited, especially at local implementation level. It is recommended that responsible institutions invest sufficient resources to address these deficiencies in order to ensure the sustainable utilisation of natural resources and to protect rural livelihoods. [§8.3]

Local economic development associated with the exploration and extraction of shale gas will likely stimulate local markets for agricultural products. Significant numbers of locally-based staff of shale gas exploration and extraction companies will increase demand for agricultural products. Shale gas operations are also likely to attract non-employees in service enterprises who will also contribute to the local economy and consume agricultural products. Operators may opt to rent land and infrastructure such as storage facilities from agricultural land users and provide significant cash incomes to them. [§8.8.1]

Shale gas exploration and exploitation will put the protection of the privacy and security of land users at risk. Currently land users enjoy high levels of control over the farm-based resources resulting in minimal losses of livestock and other property, and good levels of overall safety and security of rural communities, including land users, farm workers and their families. This is in part a result of minimal through-traffic on most farms, and relatively stable local populations. The anticipated influx of staff of shale gas companies and the situating of SGD operations on farm land will expose farm property, for example livestock, to theft and increase vulnerability of local communities to farm attacks and violence. [§8.8.2]

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 such 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 is a growing economic sector with the capacity to drive growth and upliftment in rural areas. Tourism has become the largest economic sector in in the study area in terms of number of enterprises. All study area towns are reliant on tourism, some (Nieu-Bethesda, Prince Albert, Sutherland, Loxton, Jansenville) more so than others. The rural landscape is an important resource for specialised tourism niches, such as ecotourism, agritourism, hunting and adventure tourism. This has dispersed tourism activities into the rural areas of the study area. Tourism is the fastest growing sector in most Karoo towns, thus its importance in the study area is expected to further increase in future (Fig SPM 9.1) [§9.1.2].

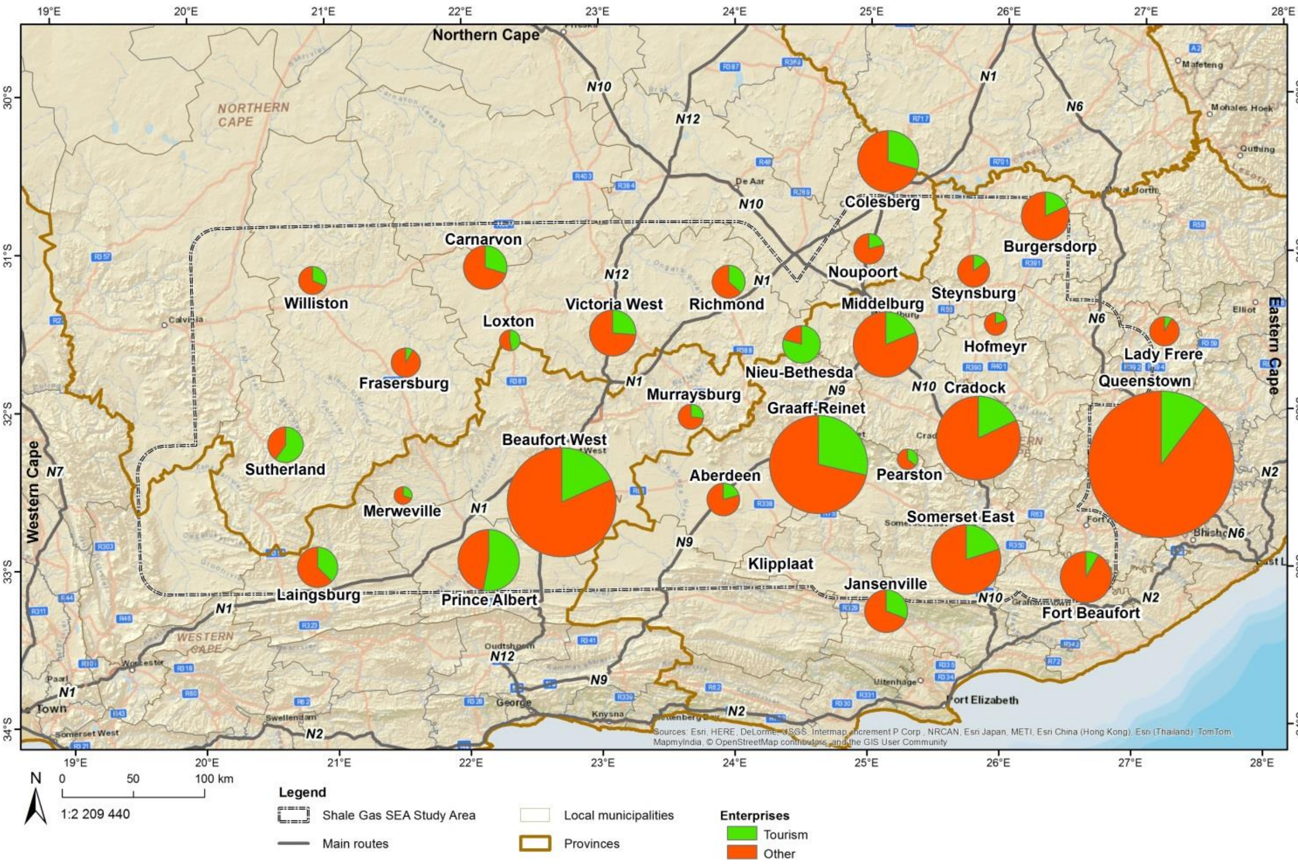


Figure SPM 9.1: Tourism enterprise numbers relative to the total of enterprises of towns in the assessment area. Circle sizes indicate the number of enterprises in each town.

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 in order to experience ecotourism, adventure tourism, agritourism, culinary tourism, hunting, stargazing, etc. 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 of the N1, N6 and N9 routes. Tourists passing through the study area would experience traffic densification and possibly also crowding out in these towns. Niche tourists are most sensitive to disruption of peace and quiet and are also the most dependent on rural areas. They would be consequently be the most sensitive SGD (Fig SPM 9.2). [§9.1.5]

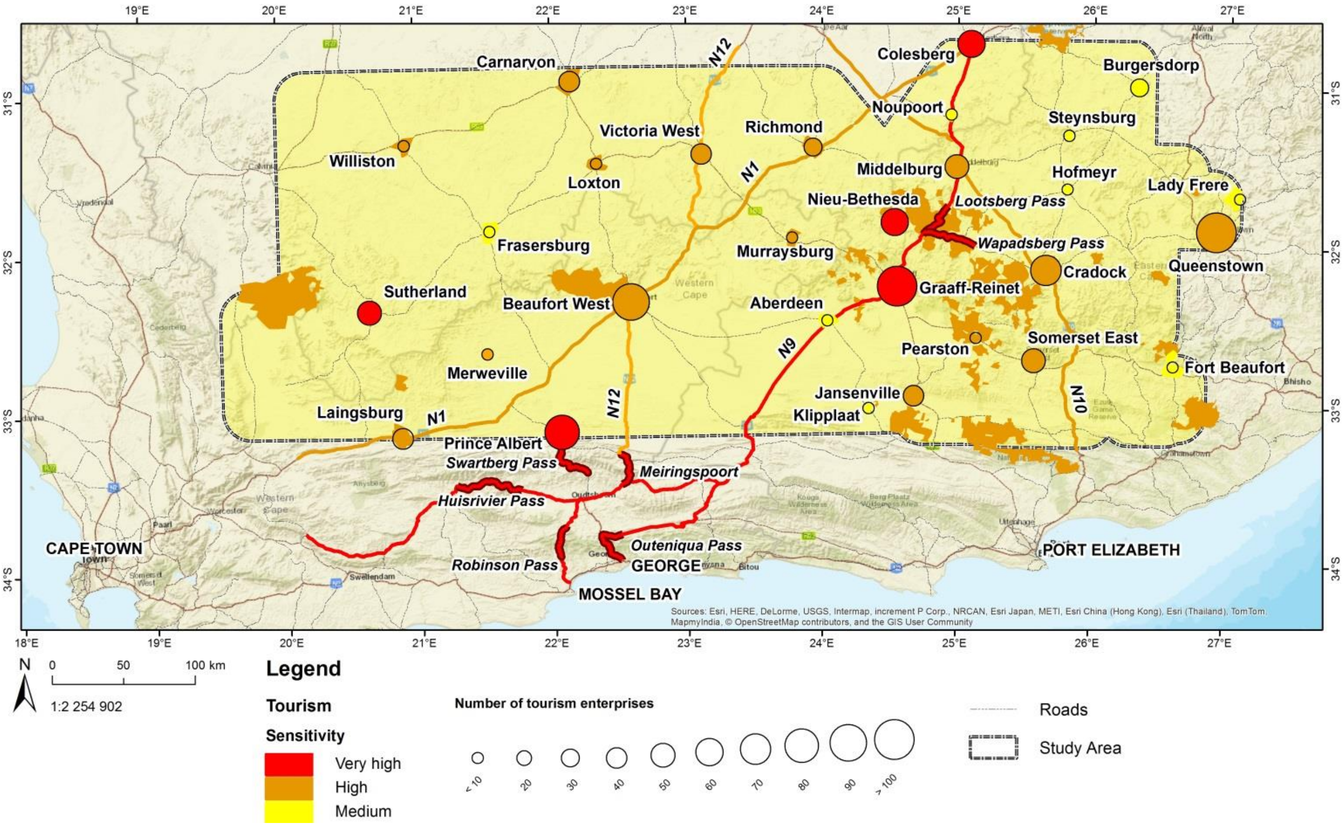


Figure SPM 9.2: Map of the sensitivities to negative impacts of SGD on protected areas, major roads and the tourism sectors of towns of and the access routes from the south to the assessment area.

The most likely negative impacts of SGD on tourism are expected to be traffic densification and its associated noise pollution. This results from slow moving trucks continuously ferrying materials needed for SGD, also through towns in the assessment area. Other impacts would include visual impacts, a loss of sense of place, potential pollution (especially 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 [§9.2.1]

Negative impacts on the tourism sector would increase the risk of losses of employment and value addition to local economies. Ranges in reduction of tourism enterprises and the associated loss in employment and Gross Value Added (GVA) are provided in Table SPM 9.1. [§ 9.2.1]

Table SPM 9.1 The losses in tourism enterprises, employment and value addition that may be associated with negative impacts by SGD on the tourism sector in the assessment area.

Loss in tourism enterprises	Tourism employment Loss	Loss in GVA R million
< 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

The negative impacts on tourism can be mitigated, requiring active cooperation between the mining and tourism industries. Options that could be used include: (i) Provision of tourism access routes protected from the heavy truck traffic associated with shale gas exploration and production. For example, the N9 could be recognised as the most important tourist access route to the assessment area and be protected from SGD traffic. (ii) Limiting shale gas traffic on mountain passes that provide access to or travel through the study area and enhance tourist experiences. These include Swartberg, Outeniqua, Wapadsberg, Lootsberg, Huisrivier and Robinson passes. (iii) Recognising that local tourist routes should also be protected from heavy traffic. (iv) The majority of Karoo towns are dependent on tourism and need to be protected to some degree. The specialist tourist towns and their adjacent rural areas are dependent on niche tourists and are particularly sensitive to SGD impacts. (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) World class practices in air, water and light pollution mitigation and management [§9.3]

Integrated tourism management would be required to deal with the complexities resulting from SGD. The current management of tourism in the study area is fragmented between three provinces and many municipalities, each with its own approach to the management of tourism. A government-led or endorsed partnership with the mining and tourism industries to collaboratively promote the region 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 eventually be funded by a tourist levy on gas production [§9.3]

10. IMPACTS ON THE ECONOMY

Shale gas development could deliver highly significant economic opportunities, but the extractive nature of SGD also brings economic risks. In both respects it is a 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 would make exports less competitive. [§10.2]

High volumes of shale gas would support an improved trade balance and reduce exposure to international market volatility and exchange rate risk. Shale gas at prices at or below imported gas would in the medium term substitute for imported gas. This would improve the trade balance and shield the country from price volatility and exchange rate risks associated with imported natural gas. [§2.1.2]

Positive macro-economic impacts particularly on the balance of payments can be expected from SGD. 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. [§ 10.2.1.2]

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, 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 per scenario

	Seismic exploration	**Exploration and appraisal drilling**	**Small-scale production (‘Small Gas’)**	**Large-scale production (‘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 % 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 Chapter 1
** Transport/trucking jobs based on truck trip numbers in Chapter 1 (these are substantially greater for the large scale production 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.

Measures focused on ownership, procurement, hiring and training are the key ways in which the benefits of SGD can be maximized, 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]

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 generally low for the scenarios considered. An important proviso is that shale gas development should not seriously compete with local water users or pollute local water supplies. [§10.2.2.2]

Local government finances are likely to be put under significant strain particularly for the large scale development scenario. Appropriate mechanisms will be needed to effectively alleviate this strain. [§10. 4]

There is a risk that the residual costs associated with SGD become the responsibility of society. Financial mechanisms will be needed 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 will be needed for land owners 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. 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

Large investments in small-town areas create boomtown conditions in the local economy. SGD under the Small Gas scenario, and especially 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. However, any threat to water quality and quantity would have significant and rapid negative consequences for local boomtown economies. [§11.4.5]

Actual or anticipated large investments in small towns will stimulate rapid in-migration of workers and work-seekers, some of them with families, which will challenge the often already-stressed capacity to deliver services. SGD will place pressure on housing, guest houses, hotels, caravan parks, and retail services. Housing demand is likely to overflow into informal settlements. Municipal planning and infrastructure provision typically has a fairly long lead time. Demands on water reticulation, electricity, sewerage, schools, clinics and local roads are likely to exceed capacity at least in the medium-term, even under intensive exploration (Scenario 1) and Small Gas. [§11.3]

Rapid development is associated with disruption of the social fabric and feelings of insecurity. The in-migration of people typically experienced in boomtowns leads to an increase in undesirable social outcomes such as teenage pregnancies, alcohol and drug abuse, property crime and violent crime. This puts pressure on the police, social welfare and health services. The challenge to local people's sense of identity and the feeling of accelerating and out-of-control change from the status quo increases the sense of insecurity and threat to the social and moral fibre of the community among local people, which could result in conflict with in-migrants and xenophobia. [§11.4]

SGD, while anticipated to raise the mean social welfare at national and local level, may perversely simultaneously accentuate social inequalities and schisms. The income earnings of some sectors, such as the local hospitality and retail services industries will rise locally. Property owners will experience a rental windfall, while poorer families may be squeezed out of their housing due to rapid and steep rental increases. There will be economic and energy security benefits outside the study area, but this could further widen the gap between those who benefit and those who mostly experience the disadvantages of higher prices, more traffic, over-taxed services and pollution. The new opportunities create the potential for new gate-keepers, both formal (such as the officials responsible for issuing permits, exposed to the temptations of corruption) and informal (individuals who set themselves up as intermediaries between government, developers and communities, competing with one another for their cut and diverting the flow of benefits from its intended recipients). Governance processes and institutions need to be strengthened to minimize such unintended outcomes [§11.5]

12. IMPACT ON HUMAN HEALTH

The health status of the present local population in the study area is below 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, would improve the health outcomes in the communities. [§12.4]

People living close to shale gas infrastructure (well-pads and roads) can anticipate negative health impacts through air, water and noise pollution. Through mitigation and exclusion zones the anticipated human health impacts on communities can be reduced. [§12.7]

SGD workers are potentially 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 well-pad is an important cause of respiratory issues. Mitigation options, such as engineering solutions and personal protective equipment, can substantially reduce the workers' exposure. [§12.12]

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. [§12.6]

Uncertainties in the chemicals to be used and evidence of the health impacts that might be expected are the major restriction in the health impact section of this study. The assessment is based on international data and experience. Many of the chemicals used in SGD do not have sufficient health data associated with them to make an assessment. Since the activity of hydraulic fracturing is relatively new in relation to the time needed to assess long-term health effects as well as trans-generational effects, scientific evidence that can be used with certainty is scant, but some of the chemical used are known to have long-term and transgenerational health effects. [§12.8]

Detection of health impacts resulting from SGD will require baseline and ongoing monitoring for air and water quality, and health, especially for health symptoms associated with SGD. This will need to be carried out prior to initiating the activity to enable ascribing any future health effects to a specific cause. Health issues should be recommended for inclusion in the Regulations for Petroleum Exploration and Production, which currently do not consider them directly. [§12.5]

13. SENSE OF PLACE VALUES

There is insufficient underlying research and documented evidence for this assessment to adequately evaluate the issue of sense of place. It describes some of 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. [§13.6.2]

There is not one, but are several, "senses of place" in the Karoo. Some of have local significance, while others are sensed by people living outside the area (for instance, by tourists), and perhaps 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 has been identified from publicly available literature or media and potential areas of conflict or sensitivity highlighted (Figure SPM 13.1). [§13.3, §13.5]

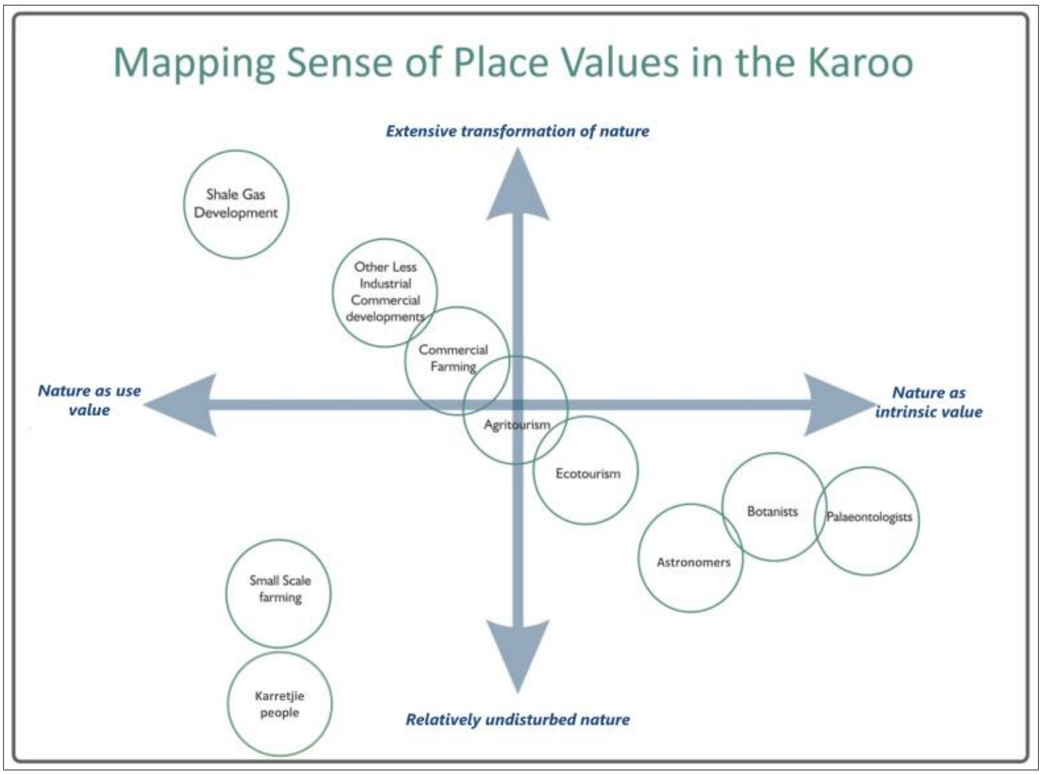


Figure SPM 13.1: Two of the key dimensions of the variation in sense of place in the study area are whether the sense of place is based on a human-transformed environment, such as towns or farmland, or on a minimally- disturbed landscape. Another dimension is the amount of priority which human needs are given relative to intrinsic values.

Shale gas development in the Karoo will affect values associated with sense of place, in some cases positively and in others negatively, and in some cases irreversibly. SGD has led to significant changes in Sense of Place in other countries, resulting in some instances in severe social disruption. Given that the inhabitants of the Karoo have lead a fairly isolated existence it is very likely that sense of place is an important element of their wellbeing, and conversely that loss of sense of place could lead to significant social disruption. [§13.5]

Sense of Place values are seldom adequately addressed in public participation processes in EIAs and development processes, 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 studies such as EIAs, Spatial Development Frameworks (SDFs) and Environmental Management Frameworks (EMFs). It is recommended that both quantitative (Likert type surveys) and qualitative (ethnographic type interviews) be applied to gauge sense of place. The results of this research should become public and made part of the processes which inform decision-making on specific SGD applications. [§13.7]

14. VISUAL, AESTHETIC AND SCENIC RESOURCES

SGD and its associated secondary developments, without mitigation, is likely to lead to the visual fragmentation of Karoo landscapes, and transformation of its pastoral or wilderness character to an industrial connotation in the affected areas. The visual impacts of SGD must be considered in conjunction with visual impacts resulting from other developments, for instance the possible uranium mining and the roll out of wind and solar energy in the study area. Mitigation consists primarily of restricting SGD activities in visually sensitive locations [§14.4]

A number of scenic 'hotspots' in the karoo could be affected by SGD. 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. [§14.4.2]

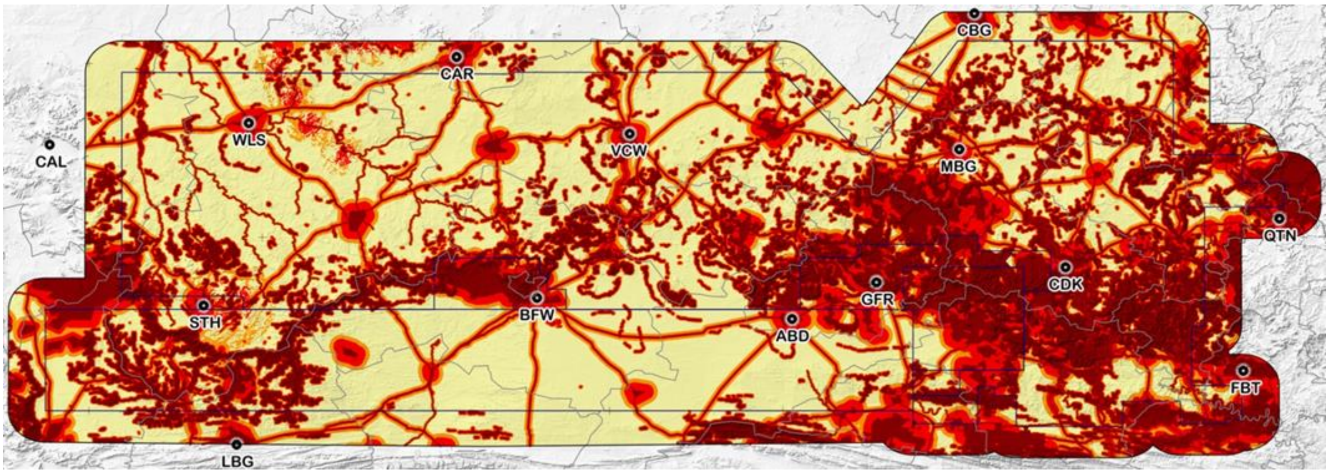


Figure SPM 14.1: Composite map of all scenic resources and sensitive receptors, including visual buffers, indicating visual sensitivity levels from dark red (the actual feature or receptor), red (high visual sensitivity) orange (moderate visual sensitivity) and yellow (low visual sensitivity)

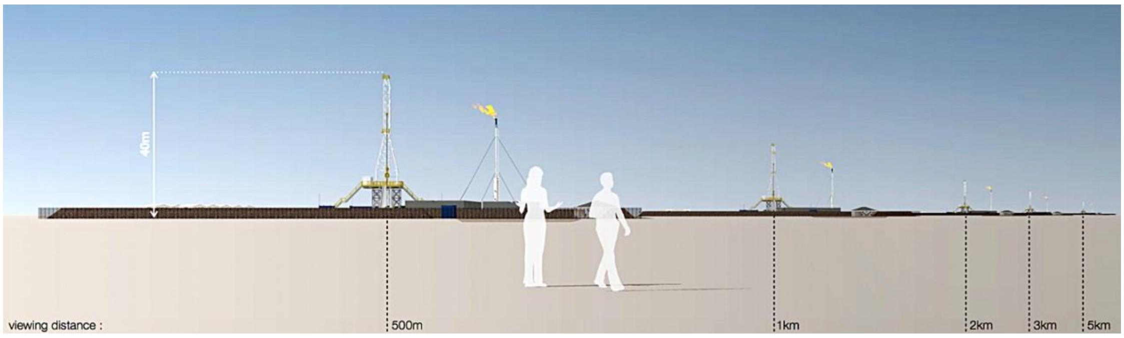


Figure SPM 14.2: Visual simulation of a wellpad during the day (top) and at night (lower) indicating visibility at a range of distances from 500m to 5km, before mitigation. The flatness and low vegetation in the karoo enhances visibility. Nightime visibility of lights and flares would tend to be pronounced in the dark rural landscape of the Karoo.

There is no standard approach to mapping or rating the value of scenic resources in South Africa. Scenic resources, and the potential visual impacts related to these resources, have significant implications for sense of place, tourism value and the regional economy, all of which are inextricably linked. Up to now there has been no precedent for SGD in the Karoo, or South Africa as a whole, and therefore there is apprehension regarding the effects that SGD may have on the Karoo landscape and its inhabitants, as well as the local tourism industry within the study area. Visually sensitive areas, including those related to protected landscapes, cultural landscapes, game farms and scenic routes must be taken into consideration when determining visual buffer zones. The scenic resources identified in this assessment correlate closely with areas of biodiversity and heritage significance as described in other sections. The escarpment is a particularly sensitive feature of the study area, although impacts of varying significance could occur anywhere. [§14.2.2]

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 well pads, 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 a generally low survey coverage the actual distribution of resources is poorly known. The small subregions which have been thoroughly explored indicate that important resources of all types can occur anywhere in the landscape, but that 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. Seismic activity could negatively affect heritage resources to varying degrees depending on their fragility, but built heritage is most at risk. [§15.4.2.2]

The impacts on heritage from the small and large SGD scenarios could be high, but are typicall confined to particular areas. There is a potential for extensive but low intensity impacts from SGD exploration. Care in the exact positioning of the infrastructure and the implementation of management and mitigation measures during all phases, as required by legislation, will help to reduce the significance of the impacts that would be experienced. The cultural landscape is the most difficult aspect to deal with in terms of mitigation. Minimising the amount of landscape scarring that takes place and effective closure phase rehabilitation are key aspects of heritage impact mitigation. [§15.4]

Current institutional capacity in terms of application of the National Heritage Resources Act (NHRA) is limited and a marked improvement will be required before SGD commences. The National Heritage Resources Act outlines procedural due diligence for heritage management and development. The status quo shows that many provincial and local authorities have yet to comply with the provisions of the NHRA. The functionality of the single national and three provincial heritage authorities overseeing the study area is highly variable and this will affect the quality of decision-making and commenting. The South African Heritage Resources Agency, as the national authority, should take responsibility for all applications related to shale gas development and source comment from relevant provincial and local authorities. [§15.1.3]

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 below the typical levels published in standards for rural areas. This is a significant difference. Subjectively a change 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. 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. [§16.2.5]

The construction, operation and decommissioning phases of SGD will likely cause noise impacts for humans and animals on sites within about 5 km of the sites. Noisy activities during the operational phases are expected to run constantly (day and night) for 6–8 weeks at a time, repeated every 6 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. [§16.2.5]

There is additionally a risk of noise impacts emanating from the surrounding roads due to increased heavy goods vehicle road traffic, especially under a Big Gas scenario, and if the roads used are otherwise quiet and seldom used. [§16.2.4]

Proposed sites of noise generating activities will need individual Noise Impact Assessments in accordance with SANS 10328 to determine the likelihood and severity of these impacts. 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. [§16.5.1]

17. ELECTROMAGNETIC INTERFERENCE WITH THE SQUARE KILOMETRE ARRAY

The permissible electomagnetic interference (EMI, “noise” in the radio frequencies) is regulated for those parts of the study area which can affect the performance of the Square Kilometer 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 north of Carnarvon, just north of the study area. The array forms a spiral with several legs, with receivers at increasing spacing on each leg. Three of the legs 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. [§17.2.1]

Electrical motors, switchgear, spark-ignited engine motors and communication devices are the types of equipment used in SGD which can potentially cause EMI. 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 minimize 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 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. [§17.4]

The key mitigation is to exclude EMI-generating sources for distances up to 40 km for the most sensitive parts of the SKA. If these mitigation actions are followed, the risk of EMI with the SKA originating from SGD is very low. [§17.4.7]

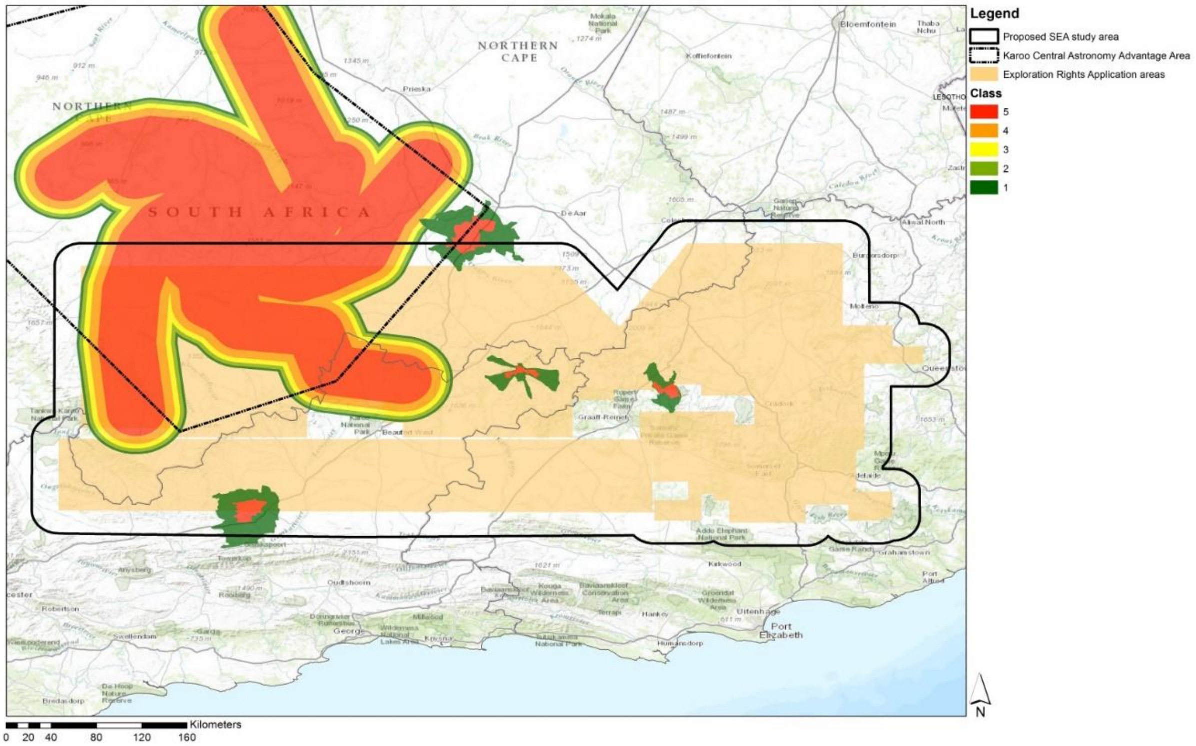


Figure SPM 17.1: SKA buffer classes are categorised from 1 – 5, where each class is informed by a specific separation distance. Hydraulic fracturing activities beyond the pre-identified buffer zones do not represent a risk of detrimental impact on the SKA as a result of EMI

Table SPM 17.1: Best practice guidelines for the mitigation for the risk resulting from SGD

	Guidelines				
Buffer Class	1	2	3	4	5
Guideline	High level site specific EMI assessment, to be undertaken by EMC specialists to identify key sources of risk. Hydraulic fracturing made subject to complying with mitigation requirements.	Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. Hydraulic fracturing made subject to complying with mitigation requirements.	Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. Hydraulic fracturing made subject to complying with mitigation requirements.	Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. Hydraulic fracturing made subject to complying with mitigation requirements.	No hydraulic fracturing activity to be undertaken.
Potential Level of Mitigation	Highest sources of interference identified and mitigated through modest shielding implementation.	Highest sources of interference identified and mitigated through proper shielding implementation. Cable routing evaluated depending on level of interference identified (cables below ground if possible).	Sources of interference across a wider frequency range anticipated. More extensive mitigation through proper shielding of higher number of equipment likely. Cable routing below ground if possible. Improved earthing to reduce interference current distribution.	Detailed implementation of shielding measures required. This includes more extensive shielding of every aperture from which interference can be generated. Greater attention to cabling and earthing required to ensure minimal contribution.	

18. INTEGRATED SPATIAL AND INFRASTRUCTURE PLANNING

Towns in close proximity to SGD activities will experience growth exceeding projections based on past trends. 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 due to increase in demand by households and local enterprises (both because of new direct jobs and spin-off opportunities), as well as high probability of increased in-migration and expected increase in indigent population. [§18.2.3; §18.3.1, §18.4.5, §10.4]

The most significant direct impact on infrastructure is expected to result from the construction of a network of geographically scattered private local access roads and well pads. Even though most of this will probably be on private land, it will have implications for the need for scarce construction materials. This will have a major impact on availability and cost of scarce raw materials such as gravel and water. Action will be required to source construction material and identify and approve local sites for extraction of raw materials. This will be accompanied with the increase in number and complexity of land development applications and required expanded technical capacity development. [§18.2.1; §18.3.1; §18.2.4]

The increase in traffic by heavy vehicles on regional roads will be substantial. This will require mitigation in terms of initial road rehabilitation to an adequate baseline and an increased cycle and quality of maintenance, avoidance of certain routes as well as development of expanded and enhanced law enforcement and safety and emergency response capacity. There may also be a need to develop pipelines and re-establish the rail infrastructure in the sub-region to reduce 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. [§18.2.2, §18.3.1, §18.4.2 - §18.4.4]

Regulatory uncertainties and limited municipal capacity to facilitate an ongoing processes of land use and land development applications associated with shale gas exploration and development could pose risks to already limited municipal governance capacity and result in regulatory bottlenecks. This could impede effective decision-making and sustainable land development. Challenges with the rolling out of the Spatial Planning and Land Use Management Act, 2013 (SPLUMA), includes: major capacity implications for municipalities; procedural uncertainty with regards to land use and land development applications; and differences in its application between the provinces, with the Western Cape Land Use Planning Act, 2014 (LUPA) applicable in Western Cape Province. Clarification of legal and implementation practices in the land use and land development regulatory framework, as well as provincial support to municipalities in development of appropriate municipal planning by laws, the update of spatial planning and land use management instruments, and the establishment of institutional capacity for municipal planning tribunals and compliance monitoring will be highly supportive. [§18.2.4; §18.4.6]

Integrated spatial planning will be essential to deal with the multi-scaled and intersectoral issues that result from activities of magnitude and duration of shale gas development and downstream development. Spatial Development Frameworks (SDFs) and Integrated Development Plans (IDPs) plans in the area will require an update. Firstly, to ensure that they consider implications of possible developments and projected growth and facilitate participative visioning, planning, prioritisation, budgeting and mitigation across possible shale gas exploration and production periods and municipal planning cycles. Secondly, to fulfil new regulatory functions, provide guidance to a range of sector plans (i.e. integrated housing and transportation plans) and enable the infrastructure pipeline necessary to design, procure, construct and maintain infrastructure. Given a host of other activities in the area, the preparation of a Regional Spatial Development Framework (RSDF) (in terms of the Intergovernmental Relations Framework Act, 2005 (IGRFA), and the Spatial Planning and Land Use Management Act, 2013 (SPLUMA)) 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 (including local communities interest groups business., and state owned enterprises such as ESKOM and SANRAL). [§18.4.5; §18.4.1].

The governance capacity for coordinated and integrated spatial and infrastructure planning, investment and management to deal with the implementation of potential shale gas exploration and development is currently limited. It is anticipated that all spheres of government (especially municipalities) will struggle to handle the increased strategic planning and regulatory challenges and implications for planning and mitigation. Creating additional capacity in all institutions is limited in terms of costs and skills availability. Given the anticipated extended timeframes, geographic uncertainty and phased approach to shale gas exploration and production activities, the establishment of regional (cross provincial) spatial and integrated development planning capacity (supported by specific task teams) could enable a cost effective shared capacity to provide the necessary technical capacity to inter alia assess applications, assist with pro-active planning, monitoring and control of impacts on land uses and activities. [§18.4.7]