The Socio-Economic and Environmental Implications of Shale Gas Development in the Karoo, South Africa

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Certificate of Research

This is to declare that, except where specific references are made, the work described in this thesis results from the candidate. Neither this thesis nor any part of it has been presented or is currently submitted in the candidature of any degree at any other University.

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Abstract

The emergence of shale gas development in the global energy landscape depicts a critical energy innovation of the 21st century. Shale gas development has significant benefits when developed sustainably; however, the shale technology is known to induce unintended impacts on the local environment. Much study has focused on explaining responses at the local and national level; however, little research has explored the role of risk perception and sociocultural factors in shaping expert and public perception of shale gas development.

This study used a mixed-method approach (utilizing a combination of qualitative and quantitative methods) to explore the underlying factors shaping expert and public perception about shale gas development and to gain a better understanding of the reasons for support and opposition to shale gas development in South Africa. The study used data collected from experts spread in different areas of the country and public participants from the four cultural groups across the Beaufort West area of the Central Karoo. The qualitative data revealed that experts were showed an ambivalent response to risk and significant support of the shale technology. The quantitative data also showed mixed results across the cultural groups with variation to risk and benefits. The White and Indian respondents opposed shale gas development on the account of significant risk on the environment. The Black and Coloured respondents showed strong support of shale gas development based on economic benefits. The study revealed that positive evaluation of shale gas development evoked support of the shale technology while a negative perception indicated opposition to the shale technology. Key reasons given by experts in favour of shale gas development are economic growth, energy independence and the assumption that shale gas could be the optimal ‘bridge fuel’ from coal to renewable energy. The study revealed that expert assessment of the risks of shale gas development is lower than the White and Indian groups. Other predictors of perception include level of institutional trust, knowledge, and access to relevant information. The observed differences and similarities between experts and the social groups are due to variations in costs and benefits perception. The findings are examined in relation to the extant literature on perceptions. The study provides an account of attitudes towards shale gas development in the Karoo to fill the gaps in the existing literature and examines potential policy implications arising from these outcomes.

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Thanks to all the participants who took part in this study. Thank you for your time, support and sharing your perspectives in the interviews and survey questionnaires. Your contributions to understanding the underlying factors shaping expert and public perception of shale gas development is appreciated. Your responses offered valued insight and help improve knowledge of the energy transition and policy formation in the South Africa context.

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My dear wife Dr Bridget Irene, you are the best part of my life. I am so blessed to have such an amazing wife. Every single day you make my day easier. Thank you, my dear wife, for being my helper. I love you so much. Because of you, my life is amazing. I want to thank you for everything that you did for me and still doing, I love you. Thank you so much for making my life so awesome.

A rainbow has seven colours. But the rainbow of our life has a million, thanks to our wonderful son, Sammy, what a bundle of joy and bond we share as a family. You are the best compliment that God has given us. You continue to amaze me in so many ways, you are such a special child, I love you so much, Sammy. The world is waiting for you, Sammy! Thank you, Jesus, for the gift of such precious and beautiful people in my life.' I could not have done it without you, Bridge and Sammy.

To God be the glory and praise.

“You can twist perception, reality won’t budge.” Neil Pearl

Dedication

This project is dedicated to my lovely wife,
***Dr Bridget Irene** and wonderful son, **Samuel (Sammy) Irene**.*
Your love keeps inspiring me.

Pa. Philip Irene
''Look beyond the empty chair
To know a life well spent
Look beyond the solitude
To days of true content
Cherish in your broken heart
Each moment gladly shared
And feel the touch of memory
Beyond the empty chair" Anonymous.
***My Sister Rosemary**.*
Never thought I'd lose you,
But here I am,
Standing alone,
Without you by my side,
We're family for life,
We promised,
But now you're gone,
I don't know what to do,
Without you,
I'm trying to hold on,
To keep strong,
But it just doesn't feel right,
I'm waiting here,
My arms wide open,
Tears running down my face,
Ready for your return,
Even if it takes forever" Adriana.

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List of Abbreviations

tcf	Trillion Cubic Feet
GDP	Gross Domestic Product
EIA	Energy Information Administration
IEA	International Energy Agency
CO_2	Carbon Dioxide
TOC	Total Organic Carbon
M_L	Local Magnitude Scale
Mw	Moment magnitude
LNG	Liquefied Natural Gas
MSDS	Material Safety Data Sheet
VOCs	Volatile Organic Compounds
R_o	Vitrinite Reflectance
GOR	Gas Oil Ratio
O/C H/C	Oxygen/Carbon/Hydrogen/Carbon
NGO	Non-Governmental Organization
NIMBY	not in my back yard
ESCOM	Electricity Supply Commission
md or mD	millidarcy
TRR	Technically Recoverable Resource
PM	Particular Matter
NOx	Nitrogen Oxide
ppb	parts per billion
CAPEX	Capital expenditure
GW	Gigawatt
R	Ran

Chapter 1: Introduction to the Research Project

1.1 Introduction

The urgency to accelerate the global energy transition from high polluting fossil fuel sources to green energy is acknowledged in literature and evidence-based policy research as embodying broader impact and coevolution of climate sustainability, energy efficiency and economic growth (Newell and Lane, 2020). The urgency attached to the energy transition has intensified with increased public awareness given the effects of anthropogenic emissions on global warming- exacerbated by high polluting energy (fossil fuel) sources (Cernev and Fenner, 2020). Governments are adopting urgent approaches and policies strategies to curb the concentration of greenhouse gas emissions and opportunities to facilitate investment in low carbon technologies (Mikulčić et al., 2019).

Technological advancements in energy development and production and their impact on renewable energies offers solution to the challenges of diversification of global and local energy sources. Although the potential of green/ renewable energy sources are theoretically unlimited, their contribution and scale to the global energy base varies with weather, location and storage potential. In countries such as South Africa, the adoption and diffusion of green/ renewable energy systems is uncertain, slow, and poorly characterized. While the need for a clear and specific objective plan toward a greener sustainable development and socially inclusive economy is necessary, however, South Africa energy policy is hindered predominately by critical social uncertainties. Policy vulnerabilities and energy/ technological diffusion is impacted by both sociocultural behavioural and relevant economic barriers. Furthermore, policy performance toward a greener transition may lead to failure if adoption barriers are not addressed or managed properly (Jacobsson and Johnson, 2000; Pegels, 2010; Negro et al., 2012). Therefore, a successful just transition requires an assessment and comprehensive understanding of people's perception and behaviour incorporated into energy policy model, a departure from the traditional cost-benefit approach often employed by governments and policy experts (Pierce and Paulos, 2012; Jacquet, 2014; Rotolo et al., 2015).

Studies have shown that disruptive energy systems are opposed and resisted by society as policymakers fail to recognize and integrate the social context of the environment into the foundation of energy planning and development. Often neglected in the extant literature is the broader sociocultural context in which the energy technology is developed and deployed. In addition, people perception may not be linear or uniform a cross geographic landscape (Carke et al., 2016). The similarities and differences including the variance in perception are discernible construct, to a large extent reflects an emerging field of investigation and key area of energy policy development. The role of community level discourse, trust, knowledge, awareness, personal/ group experiences, values, worldviews, social structure, social representation, social identity, and the complex set of technical processes related with shale gas development may hinder or facilitate the development of the shale technology. For example, international, regional, and national policy structures and frameworks may not be appropriate or successful in the local context and may exacerbate negative public perception and resistance to technological change if the policy fail to recognise and engage with the local psychological and social processes (experiences).

Conversely, a contextual institutional and policy regime that incorporates the values and interest of the local citizenry may expedite public support and acceptance of the technology (Lockwood et al., 2010). It is argued that expert and public perception about shale gas development have not been adequately researched from the local context and as a result important nuance may have been missed regarding the social acceptability of the shale technology in South Africa. The factors influencing the perception of individuals are complex and interrelated and need to be explored from a multidisciplinary perspective (Axon and Morrissey, 2020). The gap in perception is likely to delay the transition pathway. Identifying the underlying factors that influence expert and public perception and how these factors are constructed in the mind of people is important and a critical component of energy development. Empirical research of expert and public perception about energy development have generally employed a quantitative approach on a large or national scale without employing a mixed methodology (combining qualitative input) (Devine-Wright, 2008).

1.2 The Scope of the Study

Shale gas development has the potential to play an important role as a ‘transition energy’ and provide sustainable energy to vast populations in developing countries who have no access to clean and affordable energy. Although, sustainable under several conditions, most countries with significant deposit of shale gas resources have not been able to achieve its full potential due to several barriers to its penetration and diffusion. These include institutional barriers, regulatory barriers, political barriers, sociocultural barriers, technical barriers, cost effectiveness, inconsistent market conditions, political and environmental barriers. Some of the barriers may be specific to certain region, locality, or country. However, it is important to explore and identify the barriers to shale gas development in the area in which it is planned and to recommend measures to overcome the barriers (Cotton et al., 2021; Kumar and Hassanzadeh, 2021; Szolucha, 2021).

The site for this study is set in the context of public perception of shale gas development in the Beaufort West area in the Karoo, South Africa (see chapter 6, section 6.9.3). Beaufort West area is well suited for this study given the proximity to licensed area for shale gas development and level of activism in the area (Atkinson, 2021; Pietersen et al., 2021; Vermeulen, 2012). In addition, the area has significant population density comprising the four sociocultural groups and a voice on the shale gas discourse. The scope of this research sets the limits within which the study is performed and defines all aspect of the study, including the set of assumptions or thought that addresses the research questions (Johnson et al., 2007). The findings from this study represent the perception and experiences of the participants across the different socio-cultural and professional contexts. There is a need to bridge the generalization and gaps between broad empirical perspective and assumptions that hold in other geographical context to provide a more nuanced understanding of the factors shaping expert and public perception of shale gas development in South Africa. Scholarly work on how people construct their views or opinions about shale gas development is contextual and unique (Perry, 2012; Lis et al., 2015; Mazur, 2016; Evensen and Stedman, 2017; Thomas et al., 2017).

This study recognized the presence of multiple realities/ factors in society (Saunders et al., 2009; Cameron, 2011) that could contribute to shaping an individual attitude, ranging from community values, social structures, exposure/ beliefs (impacts of shale gas development from other context), individual worldview, affective/ emotive factors and place attachment (Slovic et al., 2004; Braiser et al., 2011; Fishbein and Ajzen, 2011; Heberlein, 2012; Jacquet and Stedman, 2013; Lis et al., 2015; Evensen and Stedman, 2017; Thomas et al., 2017b) and this may not be a straightforward relationship, often assumed by scholars and technical experts regarding public beliefs about the risks/ impacts related to shale gas development.

Booysen (2007) argued that the social attributes of the community characterize the identity of an individual. It is important to understand how the various cultural identities (Black, Coloured, Indian, and White) in South Africa are reflected/ represented in behaviour concerning shale gas development. The effects of race dynamics or social identity on energy development remained relatively unexplored in South Africa, presenting a new perspective of addressing public behaviour about energy development. A review of the literature shows public opposition than support in South Africa about shale gas development (Willems et al., 2016; Andreasson, 2018). For the most part, in sociological discourses, South Africa is treated as an exemplar of deepen racial inequalities shaped by the legacy of apartheid and colonial ambiguities (Seidman, 1999). The position of South Africa as deeply divided in racial identity merit a closer look in understanding the social processes shaping public attitude about shale energy development. In contrast to Western societies, South Africa reflects a theoretical bias and distinct/ unique cultural setting comprising of diverse social structures (Seidman, 1999; Seekings and Nattrass, 2008; Sisk, 2017).

In addition to exploring public perception, the present research contributes to our understanding about the underlying factors driving the perception of experts concerning shale gas development in South Africa. The expert sample represents industry and policy makers so that all the key stakeholder voices are represented in the study. The experts were recruited across South Africa. Thematic analysis was used to identify and contextualise the factors that reflect and affect acceptance of shale gas development in relation to the risks and benefits of the shale technology (see chapter 6, section 6.8.2). There is impetus to widen the scope of the study in future research to include academics, environmentalists, non-governmental organisations (NGO's) and key sector actors. Each of these themes has diverse and distinctive dimensions that are discussed as sub-themes.

In broad terms, this study critically explored contextual factors driving the perception of shale gas development in South Africa and provides a coherent theoretical framework in the way shale gas development is framed and constructed in the minds of people in the Karoo and broader expert community. More generally, there is little coherence/ scholarship in the literature exploring what constitute risk perceptions, public belief, public acceptance, or public resistance of shale gas development in South Africa. Ellis et al (2006) demonstrated the need to develop a research agenda that characterises the subjectivity and identity processes of energy development in the local context. Therefore, this body of study adopted a multi-disciplinary approach, integrating the many factors identified as shaping expert and public perception of shale gas development.

1.3 Integrated Review of Public Perceptions

The published literature on public perception has advanced knowledge that explains how individuals respond to risks posed by shale energy development on the environment (Thomas et al., 2017; Yu et al., 2018). The literature ranges from psychologically based risk perception studies to heuristics processes and functions embedded across different cultures, beliefs, and values systems (Aerts et al., 2018; Verkuyten, 2018). This field of studies has advanced an active inquiry of public attitudes assessments, including the relationship between ethnic groups and modern science, government, and industry institutions. Along these lines, public understanding of emerging energy technologies, including pollution and environmental issues, is sometimes presented as a public deficit of scientific knowledge (information deficit model) which attributes public opposition or cynicism to science and technology to a lack of understanding from a lack of relevant information (Retzbach et al., 2011; Suldovsky, 2016). Results point to the clear importance of contextual factors as a determinant of attitudes toward science and technology in contrast to the rather simplistic information deficit model that has traditionally characterized debates of this construct. This study highlights the complex and interacting nature of social and psychological factors shaping attitude towards shale gas development (Sturgis and Allum, 2004).

The recognition that public support is a prerequisite and necessary condition of shale gas development raises many questions about the processes shaping public responses. Importantly, how public behaviour is conceived and shaped has significant implications for the future of the shale industry in South Africa. Previous studies have provided critical analysis, evaluation, and insight for shale gas development in South Africa. However, the level of our current understanding of experts and public responses is limited and narrow.

Empirical research of public attitudes towards energy development has for a large part used quantitative methodology and comparative sampling techniques to characterize public responses to emerging energy development. This study employed the qualitative methodological approach using an in-depth interview to compare the quantitative data.

Several studies have portrayed ethnic/ social groups as mostly framed by contextual/ traditional knowledge and experiences (Tillman, 2002; Fuller and McCauley, 2016). Wherefore, ‘popular epidemiology' and citizen science have developed into an area of study in the shale debate that offers the need to incorporate community driven research into energy studies as a strategy of inclusive/ public participation or energy democratization, guarding the energy transition (Friedman and Rosen, 2020; Steiner, 2020).

It is also worth considering the role political incumbency plays in shaping the energy transition and the implications for energy policy making in South Africa (Meadowcroft, 2009; Laird, 2013). The influence of political incumbency is prominent in the South African energy landscape and determine the conditions under which the South African government strengthen its hegemony and agenda for sustainable-energy transition policies. Resistance to incumbent political agenda poses a significant challenge to the transition policies, given the perpetuation of the 'carbon locked in' that dominant South Africa energy mix. Therefore, the case for energy democracy is a critical component of social ownership, energy, and environmental justice, ensuring increased stakeholder participation and guaranteeing that natural or indigenous assets "flow to all citizens" equitably (De la Cruz Paragas and Lin, 2016; Fairchild and Weinrub, 2017; Atkinson, 2018; Burke and Stephens, 2018; Markard, 2018; Kalipa-Mini, 2018). Mitchell (2011) posited that the form of politics used to steer productive investments in large scale development should include multi-stakeholder groups.

The findings from this study offered implications for shale gas development in South Africa. In practical terms, the study of public perception and its effects on energy development raised several challenges related to shale gas development. Both 'local' and 'scientific' knowledge presents an opportunity to explore the more complex sociocultural and rational/ technical processes whereby experts and the public frame their perception about shale gas development (Gasper, 1996; Irwin, 2013).

1.4 Evolutionary Perspective of Shale Gas Development

Published literatures suggest that organic-rich shale formations are widely distributed in sedimentary basins (Fig.1). Countries with commercial reserves are exploiting their shale resources as alternative energy source to mitigate a range of environmental, economic and energy concerns. The potential benefits of shale gas development rehearse the principal claims and case for its adoption as a 'bridge fuel' (Jones et al., 2013; Gong, 2020). Delborne et al. (2020) affirmed the role shale gas could play as a short term ''bridge'' to a green future.

Evidence of aggregate GHG emissions from modelling projections offers suggestions that shale gas decreases greenhouse gases than coal energy and reduced impact on climate change. To make a comparative analysis, emissions will need to be evaluated and accounted at specific levels in the life cycle of processing, distribution, and combustion (Cathles et al., 2012; Newell, and Raimi, 2014). Complementary studies by Newell, and Raimi (2014) further noted reduction and emission controls resulting from "green completion" standards on shale gas development compared to coal and petroleum products.

The potential of shale gas substituting coal is challenged by Howarth et al. (2011) and others as lacking methodological rigour. A study by Howarth et al. (2011) posits that 7.9% of anthropogenic methane produced from shale well is likely to escape into the atmosphere, negating the long-term sustainable benefits to society relative to coal for electricity generation.

Further studies have noted that shale wells are more ''leaky" than coal and that the benefits of shale gas development are overtly exaggerated based on optimistic assumptions (Cathles et al., 2012; Renner and Giampietro, 2020). Interestingly, attitude to shale gas development in South Africa is framed on two streams; risks posed by shale gas development on the local environment and the benefits of shale development in terms of economic growth, job creation and security of supplies (Fig and Scholvin, 2015; Willems et al., 2016; Andreasson, 2018).

Given the environmental concerns and unintended consequences associated with shale gas development, Thomas et al. (2017) highlighted the contested nature of shale gas development in shaping the futures of sustainable energy development which could further bring intrinsic values to the different stakeholders in South Africa. Meyer and Schulz-Schaeffer (2006) highlighted the dynamics of sociocultural factors in broadening the energy policy agenda in South Africa. Sociocultural factors could be a determining factor on whether to adopt the shale technology in South Africa.

Goldthau and Sovacool (2016) argued that the value of shale gas development should not be based on the technical merits alone but a process of multilevel perspective and social innovation, arguing that technological diffusion should take a social practice theory framework. Hölsgens et al (2018) posit this perspective as valuable in understanding the transition process. Several studies have argued along this line, noting that the concept of interpretative frames, heuristic, niche, and social construction is suitable typology (as an integrated approach) in exploring the sociological and historical context of energy technology (Russell, 1986; Leonardi and Barley, 2010; Bijker et al., 2012; Sovacool and Brown, 2015). We understand that frames are not new but exist in the social dimension of energy development established within the relevant social groups (social networks) in the community (Hayes and Knox-Hayes, 2014). The distinct cultural identities embedded in a community characterize the relevant social groups (Black, Coloured, Indian, and White) in South Africa. The social groups make up the environment in which the energy system is deployed. Therefore, the environment plays a critical role in legitimating the value of the technology. Kerr et al. (2017) argued that social groups give meaning to shale gas development. Smith and Kern (2009) highlighted the critical role interpretative flexibility plays in shaping the social consent of the transition without threatening the values and interest of the community (Sovacool, 2014; Goldthau and Sovacool, 2016).

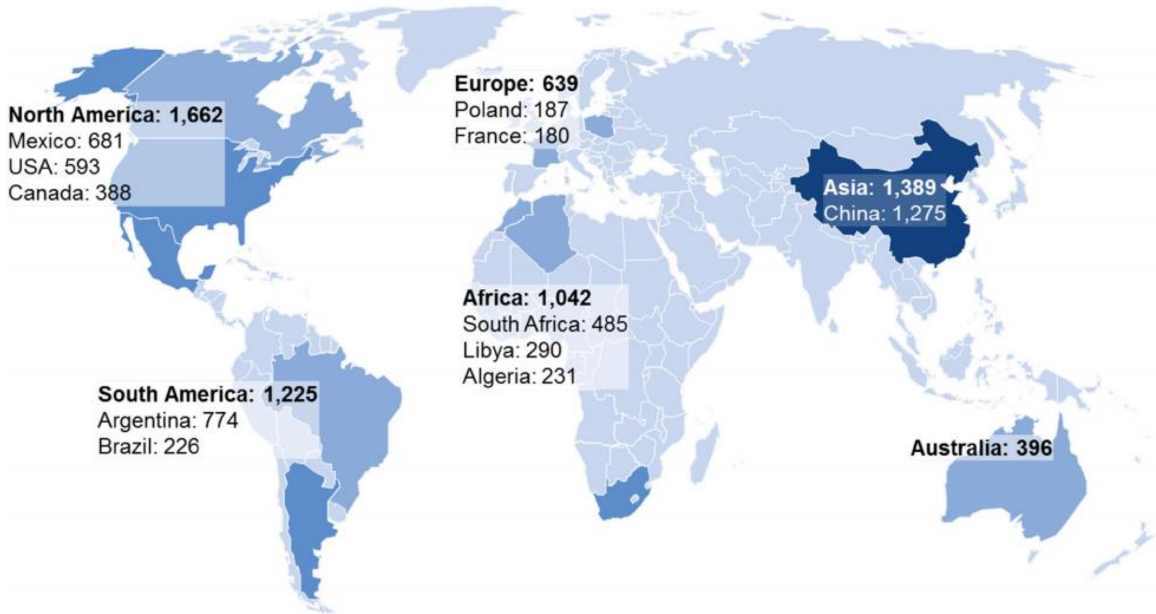

Figure 1: Estimates of Technically Recoverable Shale Gas Resources in Selected Countries

(1 trillion cubic feet= 28, 316, 846, 592 cubic meters (SI base unit).
Russia and the Middle East are omitted. Source: Inderwildi et al. (2014).

1.5 The Local Context

A critical component of sustainable energy development is the growing need to satisfy local, national, and international demand of energy supplies. Particularly energy systems that is both equitable and supported by the local population. The aim of this study is to explore how energy development is framed within the local community. In-depth survey and face-to face interviews were conducted to better understand the perception of experts and residents in the Karoo concerning shale gas development. The findings of this study demonstrate the combination of complex sociocultural, local values, community relationship and psychological factors responsible for shaping support or opposition to shale gas development in the Karoo.

Policy makers and energy researchers have recognised that technological/ energy adoption is framed by the local context, i.e., the environment in which the new energy development is deployed. Such perspective negates the concept of technological determinism, the notion that technological adoption is accepted on the basis and response to energy needs or mitigation of environmental hazards without recognising the role sociocultural factors and local values plays in shaping perception and general attitude toward the shale technology (Boyd and Paveglio, 2015). Extant literature refers to the success and acceptance of energy technology based on economic, technical, and political values (Wajcman, 2002; Liss, 2012; Golden and Wiseman, 2014). However, these constructs are interwoven and applicable to a specific geographical context described as sense of place. Therefore, technological adoption/ energy development must be considered within the sociocultural, historical relationship, political and environmental context in which they situated (Boyd and Paveglio, 2015). The study area (Beaufort West) has previously experienced levels of natural extractive activities of coal mining (Fig. 2, Chapter 6, section 6.9.3) (Vermeulen, 2012; Geel et al., 2013 Nülle, 2015; Downie and Drahos, 2017; Andreasson, 2018).

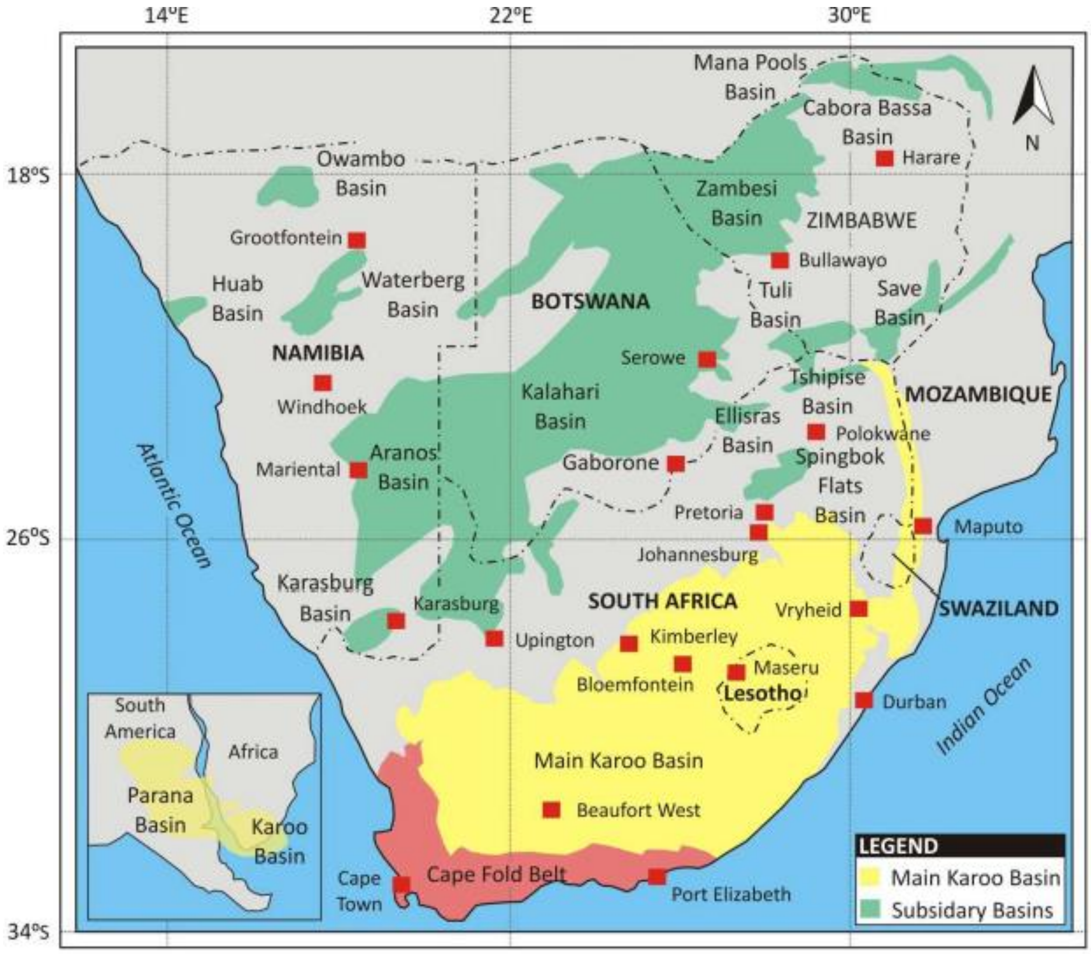

Figure 2: Map showing South Africa Shale Basins and Study Location (Beaufort West)
Source: Black (2015).

1.6 The Rationale for Expert and Public Perception

The recognition that perception is a prerequisite and condition for the social acceptance of energy development raises many questions about the potential factors and social processes shaping expert and public perception and attitude towards the shale technology.

Most studies on energy planning and development are forward looking and do not put much consideration or emphasis on the social drivers and the wide range of complex social interactions in the community as shaping the acceptability of shale gas development (de Groot et al., 2020; Walton and McCrea, 2020; Kânoğlu-Özkan and Soytaş, 2021). Most studies make a broad generalization about expert and public attitude about shale gas development in South Africa by applying western assumptions and broad theoretical assumptions to the South Africa context failing to contextualise the South Africa setting as uniquely distinct geologically and different in the social structure. The social structure in South Africa is not homogenous or linear but made up of distinct, and complex sociocultural groups (Black, Coloured, Indian, and White) and deeply radicalised (Rogerson, and Rogerson, 2020; Pirtle, 2021). Therefore, the drivers of public support regarding shale gas development extends beyond the centrality of technological innovation, international/ national energy, and environmental policy agenda. Understanding these dynamics, perspectives among the social groups, and the subjective factors underlying experts' perception in the energy landscape of the Karoo is critical in policy making and siting of new energy development. The drivers are not independent but relate or interwoven in a complex ecosystem of sociocultural values, briefs, institutional trust, awareness, heuristics processes, experiences, worldview, perception, and frames requiring citizens science and energy democratization to resolve. Scott (2002) argued contrary, noting that integrating public participation in academic and policy studies is controversial given the constraint of time and enormous resources allocated to the science of public perception.

This study recognised the concept of competing interpretative frames as an aspect of perceived reality among the social groups in modifying and communicating risks and the meaning of shale gas development. Therefore, the ability to modify the concept of shale gas development regardless of the technological design is critical to the deployment of the shale technology in the local setting. The study also acknowledged the discursive approach as a shared way in which the social groups apprehend the world around them with each discourse resting on a set of cultural assumptions and judgements which provides the basis for debates and contentions in the energy landscape.

Perception shapes an individual belief and is affected by prejudices, cultural biases, and flawed scientific assessment. However, public perception may not necessarily be incorrect. An individual can receive verifiable information to form an objective opinion of concepts and notions (Viviani and Pasi, 2017).

The study of public perception is vital in many ways, specifically where energy development and sustainability improvements are needed through public debate and social representation. Morgan (1997) claimed that the benefit of public perception is essential to get a better understanding of the underlying factors. In many cases, the deployment of complex energy systems in a community is limited or hindered without a comprehensive assessment of public perception about the potential risks to the environment. The development of a risk assessment plan incorporating public opinions is a crucial and effective strategy in managing and communicating risk. The study of public perception in energy development also plays a significant role in optimizing project cost and allocating the right amount of resource to planning and development (Rogers et al., 2008).

The contrasting trends and uncertainties and lack of consensus among expert reflects the contentious nature of shale gas development. Many factors such as paucity of empirical/ baseline data, functional factors, structural factors, constraints in measurement standards, limited understanding of the processes involved in shale gas development, mix of subjective, social, and personal factors and political considerations have significant implications to the future of shale gas development (Evensen, 2015; Montpetit and Lachapelle, 2017; Williams and Sovacool, 2019). This study recruited geologist, drilling engineers and policy makers involved in the shale gas discourse to give their perception and multi-interpretability understanding of shale gas development in the Karoo. The study found a high level of variance among expert's perception suggesting a deep and an ongoing contestation about shale gas development in the national context. Theoretically, the study utilized an integrative approach to the related frames and arguments put forward by the experts to analyse the underlying factors shaping the perception of experts regrading shale gas development.

1.7 The Role of Public Engagement and Community Ownership

The role public engagement and community ownership plays in energy development provide a new understanding of the factors underlying the social acceptance of shale gas development. Based on empirical studies, public engagement indicates that community driven energy development shifts the focus from economic, environmental benefits and technical merit to a more diverse and complex set of drivers. A key benefit of public engagement for the local communities in energy development is that it offers the local community the opportunity to influence policy, planning and development rather that benefits. However, it is not a silver bullet to securing the license to operate and to resolve the issues that raises from how energy resources should be planned and developed in the local setting. While the energy transition has become necessary for most countries, the question remain on how to deliver energy that is both equitable and socially acceptable (Dryzek 2010; Niemeyer, 2013; Simis et al., 2016; Suldovsky, 2017; Muradova et al., 2020; Pellegrini-Masini, 2020).

Recent scholarship regarding the morality and conceptualisation of energy equality have demonstrated for the need to incorporate citizens participation in the energy transition not just as beneficiaries but co-owners, a significant step in reducing energy inequality and securing the social license to operate in the local community (Pellegrini-Masini, 2020).

1.8 Gaps in Extant Literature

Individual and group actor processes in energy development are not linear but disruptive processes that plays a critical role in shaping the energy transition and justify further studies. In some cases, radical technological innovation has been noted to generate complex structural changes in society. Studies have argued that the transitional processes are exercised across contexts incorporating the identity of actors (Becker et al., 2021). Rarely are the social groups that links individuals in a community given much consideration (Bögel and Upham, 2018). Hence this present study explores the role of shared identity, shared meaning, and the inherent relationships between the groups in framing individual perception and participation regarding shale gas development in South Africa. We understand that values vary substantially among different social groups which accounts for differences in individual and community perception toward energy development (Clayton and Opotow, 2003). Therefore, the concept of social identity underpins individual and community behaviour related to new energy development and improves our understanding of how individual perception is framed and various responses to shale gas development. Geels (2012) emphasized that social identity constitutes a key driver to energy and sustainability transition. Similarly, Clayton and Opotow (2003) found that environmental identity represents a critical aspect of community life which helps to facilitate the perception of individuals in a community. Environmental identity is linked to sense of place, individual connection to the physical environment, based on emotional, cultural, and historical attachment to the environment. However, this study focuses on the element of social identity or group norms in shaping behavioural changes toward shale gas development (Hogg and Reid, 2006). Hogg and Reid (2006) argued that group norms or values are shared construct and a cognitive depiction of behaviours and responses of specific social group distinct from other groups. Every social group is characterised by specific sociocultural values or internal biases (theoretical biases) which makes individual behave in a certain way that is consistent with the values of the group (Fielding et al., 2008; Becker et al., 2021). This makes a compelling case for further studies regarding public perception of shale gas development in the Karoo, given that social behaviours are deeply rooted psychologically and resistant to change (Baum and Gross, 2017; Becker et al., 2021).

This current study builds on the premise of psychology of shared identity in understanding how group biases shapes individual perception regarding shale gas development in the Karoo. This approach is consistent with studies undertaken in framing sociotechnical transitions and innovations (Gaertner and Dovidio, 2014; Baum and Gross, 2017; Upham et al., 2019; Becker et al., 2021). In terms of future work, several points highlighted in this study merit additional consideration in different context.

1.9 Research Aims and Objectives

This study aims to contribute to the body of literature in the following:

1. To critically explore the environmental, social, and economic impact of shale gas development.
2. To critically review the geological understanding regarding shale gas development and evaluate the resource potential, risks and uncertainties of the Karoo Basin.
3. To critically explore and compare the perception of experts and residents' response to risks and benefits of shale gas development.
4. To critically explore the differences in expert and public beliefs about shale gas development.
5. To critically explore the factors that influences shale gas development among the experts and the various social groups in the Karoo.
6. To critically explore the effects of technical merits and social identity as a predictor of individual behaviour toward shale gas development.

1.10 Research Questions

The following research questions were used to achieve the research objectives:

1. RQ 1. What are the perceptions and responses of expert and the public regarding the risks and benefits of shale gas development, does the perceived risks outweigh the potential benefits?
2. RQ 2. Is there a direct correlation, differences, or relationship between the measured constructs to behaviour of experts and social groups towards shale gas development?
3. RQ 3. To what extent does expert judgement affect or compare with public perception

about shale gas development?

4. RQ 4. To what extent does the public perception of shale gas development in South Africa compare with the US and the UK?

These questions address the gaps in the literature that was used to achieve the research aims and objectives. This present study examined the perception of experts (technical and policymakers) in South Africa and the public/ ethnic groups in the Karoo where shale gas development is proposed. Shale gas development in the Karoo is an emerging shale play currently under moratorium. The study explored the factors shaping the perception of individual about shale gas development and has significant implications for policy making and widening the transition and shale gas development debate in South Africa.

1.11 Major Areas of Contributions

This present study contributes to five thematic areas in the sociotechanical transition studies:

- how group norms and values are represented as context dependent construct in shaping public perception regarding shale gas development. The theory of social identity informs the framing of individual-level processes in issues related to shale gas development.
- societal culture are a core concept in shaping public behaviour and the energy landscape, this perspective should be considered in framing energy policy and planning. This adds to the growing evidence of subjective human experiences and multi dimensional factors shaping public perception.
- explains how risk is perceived about shale gas development.The riskiness of shale gas development is uneven and assessed differently by different individuals manifesting as value or cost induced biases.

These contributions have significant relevance to social scientists, policymakers, and energy scholars.

1.12 Structure of the Study

This study addressed the sociotechnical processes, socio-economic and environmental impacts of shale gas development in the Karoo (Figs. 2 & 3). This study incorporates a comprehensive assessment of peer-reviewed academic and relevant industry literature, including information released by the South Africa government.

The thesis is structured into eight chapters shown below (Fig. 3):

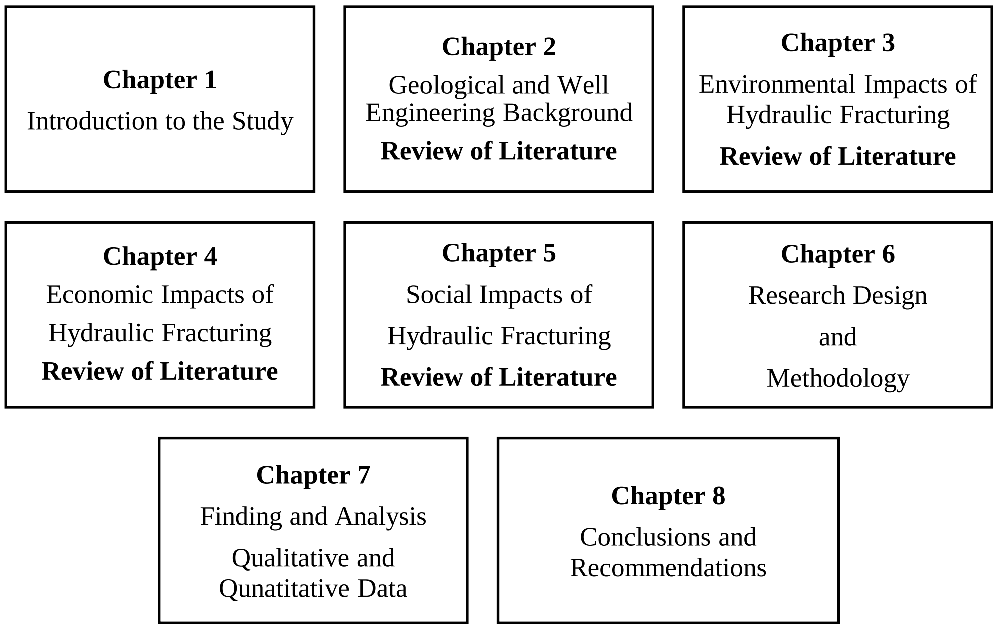

Figure 3: Structure of the Study.

Chapter 2: described the geological consideration of the Karoo Basin and increases our understanding of the technical processes involved in shale gas development, including directional drilling and hydraulic fracturing processes, including the rationale for scientific studies and further exploration in the Karoo Basin to reduce the geological uncertainties.

Chapter 3: focused on scoping work to assess what pathway or channels can give rise to significant localized and broader environmental impacts. The rationale of environmental sustainability and transition pathway are discussed extensively as fundamental attribute of social and economic sustainability.

Chapter 4: contributed to the broader debate of economic sustainability of shale gas development, review of direct and indirect economic impacts, including economic uncertainties, boom-bust effects and wider benefits to the local economy.

Chapter 5: drew from a long tradition of studies about energy boomtowns and disruptions to explore the social and community impacts of developing the Karoo shale resource, including a thorough understanding of historical social/ ethnic cleavages in South Africa distributional injustice, mechanisms of local activism and solidarity is presented.

Chapter 6: presented the study within the mixed-method approach and provides the rationale and application of multiple methodologies and theoretical framework for data collection, analysis, data quality and interpretation of the findings. This chapter also described the research setting and sampling criteria.

Chapter 7: described the findings of the qualitative and quantitative study. This chapter also compares the results to historical and extant research undertaken in public perception studies of shale energy development.

Chapter 8: reflect on the study's contribution to the knowledge and practice of shale gas development. This chapter highlights gaps for future research and provides recommendations for policymaking if shale gas development moves forward.

1.13 Conclusion

Social scientists and energy scholars are increasingly interested in exploring how the perception of risk and social factors influence the acceptability of shale gas development. Over the last decade, three thematic areas have been dominant concerning the shale gas discourse: the impacts of shale gas development; the role of perception in defining the social acceptability of shale gas development; shale gas in the energy transition (Boudet et al., 2014; Jaspal and Nerlich, 2014; Cuppen et al., 2019).

The need to understand expert and public attitude is critical for several reasons; from a policy perspective, social representation and acceptability represent a significant barrier to the development of shale technology (Vermeulen, 2012). There is justification for this present study broadening on a range of perspectives that can formulate democratic energy policy as reflected in community interest and values. No research to date has explored and compared both expert and public perception about shale gas development in South Africa. This study is increasingly important as public debates about shale gas development permeate the Karoo community.

Why do we have these gaps in literature? The difference is grounded in how expert and the public frame their perception of risks and benefits reflected in attitude about shale gas development. Attitude is characterized as a hypothetical/ theoretical construct that describes an individual's level of like or dislike for a thing. In simple terms, attitudes are opinions or prejudices, generally represented as positive or negative perspective of an individual (Schwarz and Bohner, 2001). Attitude is inferred from an individual assessment and responses to issues. Accordingly, the processes involved in evaluating the attitude of expert and the public are central to this study, together with inferences about the level of acceptance across the various social groups in the Karoo. Empirically, the dynamics and measurement of attitude are contextual and reflects a multidimensional process (Sjöberg, 1999; Schwarz and Bohner, 2001; Crowe et al., 2015; Luke and Evensen, 2021). Therefore, this research contributes to the literature by addressing these gaps by sampling expert and non-expert/ public perception. This current study provides robust data and explores the relationships of key drivers of perception, an essential consideration of the risks and benefits concerning shale gas development.

Chapter 2: Geological and Well Engineering Background

2.1 Introduction

Shale energy sources refer to the accumulation of hydrocarbons trapped within thick organic-rich black shales (in non-conventional reservoirs, sedimentary rocks with low porosity and permeabilities) whose commercial exploitation and access requires complex drilling and enhanced well stimulation techniques (utilizing well-placement and reservoir optimization comprising) of horizontal drilling and hydraulic fracturing technologies. The 'shales' are deposited primarily as sedimentary rocks in geological depo-basins referred to as ''shale plays'' (Figs. 1 & 2) (Boyer et al., 2011; Torghabeh et al., 2019; Milkov et al., 2020). The 'shale plays' are widely distributed and extend over large geographical areas and prospective sedimentary basins spanning across North and South America, Europe, Asia, and Africa continents and exhibit similar petrophysical and geological characteristics (Figs. 1 & 2) (Wang et al., 2014; Du and Nojabaei, 2019; Milkov et al., 2020).

Natural gas account for over 24 % of the global energy consumption with the US shale boom accounting for the largest (two-third) share of global natural gas production, spurring ''the golden age of gas'' (Shafiee and Topal, 2009; Arutyunov and Lisichkin, 2017; Lin and Xu, 2020; Carson, 2021). The US shale revolution have propelled the most rapid and largest surge in energy production and fundamentally changed the global energy landscape underpinned by directional drilling and hydraulic fracking activities. Advances in unconventional drilling technologies and reservoir management has unlocked vast reserves of shale resources previously thought to be geologically inaccessible and uneconomical to develop. The shale boom has profound implications regarding national energy policies and relevance to global strategic sustainable energy development (Bentham, 2014; Cherif et al., 2017).

Studies have demonstrated that investments in shale gas development mirrors high risk/ high reward in exploration and production of natural gas. Shale wells reach full production profile quickly (on average of 70,000 thousand cubic feet (mcf) per day in the first few days) compared to conventional gas wells which produces nearly 30,000 mcf, however significant shale wells are required to achieve economic viability. The prospectivity of shale resource depends on several factors ranging from the kerogen type, hydrocarbon generating potential of the basin, thermal maturity of the kerogen, rock mineralogy and depositional environment (Agrawal and Sharma, 2020). Findings from petrophysical studies have demonstrated that gas production for individual shale wells varies significantly across the different geological basin and during the well's life cycle (Tripoppoom et al., 2020) (Fig. 1). Majority of unconventional wells declined by about 70 %, first year after initial well flow (Newell and Priest, 2017). This demonstrates steep decline curves of shale gas wells which is commonly discussed in literature.

The EIA estimated that shale resources in 41 countries account for 137 prolific shale basins and represent 32 % of global natural gas technically recoverable resources (EIA, 2013). However, the assessment of global technically proven recoverable shale resources is uncertain given that new ‘shale new plays’ are emerging, while old and matured ‘shale plays’ are rapidly declining.

South Africa accounts for 5.1 % of the world total TRR concentrated within the Ecca Group (Whitehill Formation, Prince Albert Formation and Collingham formation) in the Karoo Basin (Fig. 4). However, several studies have reported inconsistent shale gas resource in the Karoo Basin, studies carried out by De Kock et al. (2017), and Chabalala et al. (2020) suggested an estimated TTR 13Tcf. Given the thermal and tectonic conditions that prevailed during the evolution of the Karoo Basin. Studies noted that the Karoo Basin holds a conservative resource potential between 20 Tcf-50 Tcf (Econometrix, 2012). Vermeulen (2012) argued that basin-wide/ exploration drilling activities are required to fully appraise the geological risks and economic potential of the Karoo Basin. This is unlikely due to the current moratorium imposed on shale gas development in the Karoo (Steyl and van Tonder, 2013; Scholes et al., 2016) (Fig. 4).

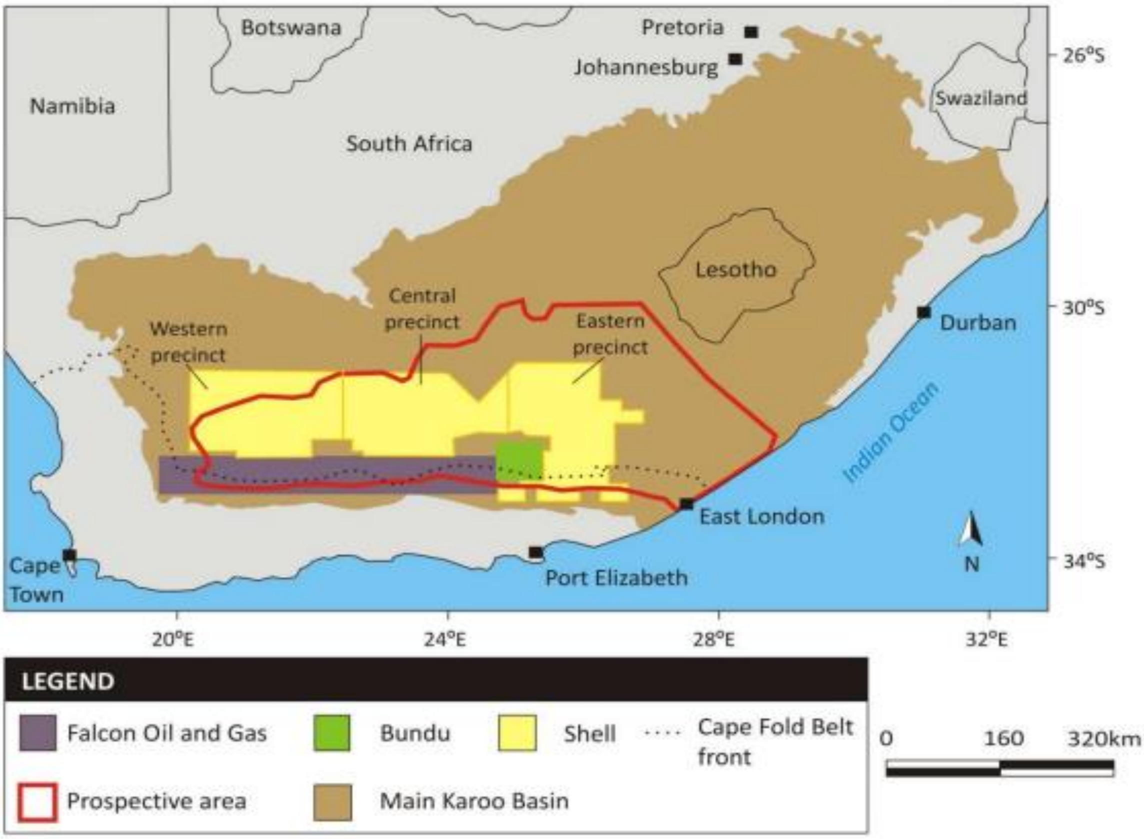

Figure 4: Karoo Basin and Technical Cooperation Permit areas.
Source: Black (2015).

2.2 Geological Setting of the Karoo Basin

The Karoo Basin in South Africa covers a surface area of approximately 700,000 km^2 of 100 Ma of sedimentation ranging from 280 to 180 Ma (Johnson et al., 2006; Neveling et al., 2016; Baiyegunhi and Gwavava, 2017) (Fig. 5). The development of the Karoo Basin covered two-third of the area of South Africa and evolved from the initiation and final breakup of the Gondwana supercontinent between the Late Carboniferous to the Middle Jurassic (Geel et al., 2013; Mckay et al., 2015). The Karoo Basin developed from the amalgamation of two separate tectonic activities juxtaposed between the southern and northern active margin of the Gondwana (Catuneanu et al., 1998).

The southern tectonic events are thought to be associated with the activities of subduction and orogenesis along the paleo pacific rim of the Gondwana that resulted in the development of a retro-arc foreland referred to as the ‘‘Main Karoo Basin’’ followed by a flexural and dynamic loading of sediments (Lindeque et al., 2011; Bamford, 2016) (Figs. 5 & 6). The northern episode was activated by extensional forces that developed southwards from the Tethyan margin of the Gondwana. It is understood that climate fluctuations of cold and semi-arid to humid conditions during the Late Carboniferous to Earliest Permian initiated the development and formation of the stratigraphic and structural architecture of the Karoo Basin (Catuneanu et al., 2005) (Fig. 6).

The idea that tectonic control contributed to the development of the Karoo Basin was suggested initially by Rust (1973) and subsequently acknowledged by Smith et al. (1993); Veevers et al. (1994); Johnson et al. (1996), and Tankard et al. (2012). Studies have suggested that the development of the retro-arc foreland Karoo Basin led to the evolution of a fold-thrust belt of magmatic origin (Visser, 1987; De Wit and Ransome,1992; Veevers et al., 1994; Catuneanu et al., 2005) (Fig. 6). Tankard et al. (2012) proposed a tectonic-sedimentary development of the Karoo Basin illustrated by subdividing the Karoo Basin into a pre and foreland segment. The Cape Supergroup evolved during the Early Ordovician to Early Carboniferous and made up of approximately 8km of shallow marine, deltaic and fluvial sediments which thickens in the southern axis of the east-west depo centre (Rust, 1973; Veevers et al., 1994; Turner, 1999).

Earlier studies suggested that the sediment of the Cape Supergroup originated in the north from a cratonic source (Tankard et al., 2012). Studies noted that the overlying Karoo Supergroup consists of approximately 12 km of deep marine to fluvial sediments (Baiyegunhi and Gwavava, 2017). Stollhofen et al. (2000) attributed the Karoo Basin as an extensional intracratonic rift trending in the N-S direction to the shear zone of the basement rocks. Chevallier and Woodford (1999) and Svensen et al. (2007) observed several structural features, faults, and intrusions such as dolerite embedded as dykes and sills. The authors noted that the dolerites and structural features were formed during the tectonic evolution of the Karoo Basin. Woodford and Chevallier (2002) proposed lithological control on the development of dykes. Woodford and Chevallier (2002) found that the dykes were strata bound and clustered in the Upper Ecca and Beaufort Group. Chevallier et al. (2001) found structural deformation in the Main Karoo Basin trending in three different directions, Western, Eastern and Northern sections. The risk posed by the deformational and tectonic activities in the Karoo Basin led to the development of dolerite intrusions that may have produced channels for releasing formation gas. Well test data from CR 1/68 borehole found oil shows and a small presence of gas in the Whitehill Formation (Rowsell and De Swardt, 1976; De Kock et al., 2017).

Stratigraphically, the Karoo Supergroup is subdivided into five groups; the Dwyka (Late Carboniferous), Ecca (Early Permian), Beaufort (Late Permian—Middle Triassic), Stormberg (Late Triassic—Early Jurassic), and Drakensberg Groups (Middle Jurassic) (Johnson et al.

2006; Tankard et al., 2009; 2012; Flint et al., 2011; Poyatos-More´ et al. 2016). Johnson et al. (2006) proposed that the Middle Jurassic period experienced rapid environmental conditions coupled with tectonic activities, uplift and eruption of basaltic lava overlying the Drakensberg Group (Fig. 7).

The Ecca Group were derived from marine turbidites and submarine fan origin (Catuneanu et al., 2005). The clays and mudstones in the Prince Albert Formation were deposited as diamictite, mainly marine sediments derived from the Dwyka Group derived from the SE part of the Karoo Basin (Johnson et al., 1996). This was followed by the deposition of the Whitehill Formation, predominantly formed as carbonaceous shale overlying the Collingham Formation made up of grey shales, and yellow claystone, the deposition of the Ripon Group followed this made up of sandstones and shales. The Fort Brown Formation and Waterford Formation were deposited as submarine fans, shelf, and deltas (Milani and de Wit, 2008; Tankard et al., 2012) (Table 1). This interpretation is consistent with the findings of Van Lente (2004), who observed a progressive trend of sediment thickness and low rates of sedimentation during the deposition of the Lower Ecca Group. Hansma et al. (2016) noted that the Cape Orogeny occurred as two separates deformational episodes; the first event occurred at about 275–260 Ma, while the second one at about 255–245 Ma. The southern Cape Fold Belt occurred synchronously with the deformation of the Cape Folds and sedimentation in the foreland basin (Catuneanu et al., 2005; Paton et al., 2006) (Fig. 6). Van Lente (2004) observed rocks of batholith origin in the Ecca Group formed from the amalgamation of subduction-related plutons from the Late Jurassic.

Figures 5 and 6 shows the deposition of the Ecca Group during the evolution of the Karoo Basin. Both figures demonstrated that the southern trough of the Karoo was developed by the down warping of the Cape Fold Belt followed by subsequent uplift along with the CFB, noting that the paleo-environment switched to non-marine and created an influx of deltaic sediments (Veevers et al., 1994).

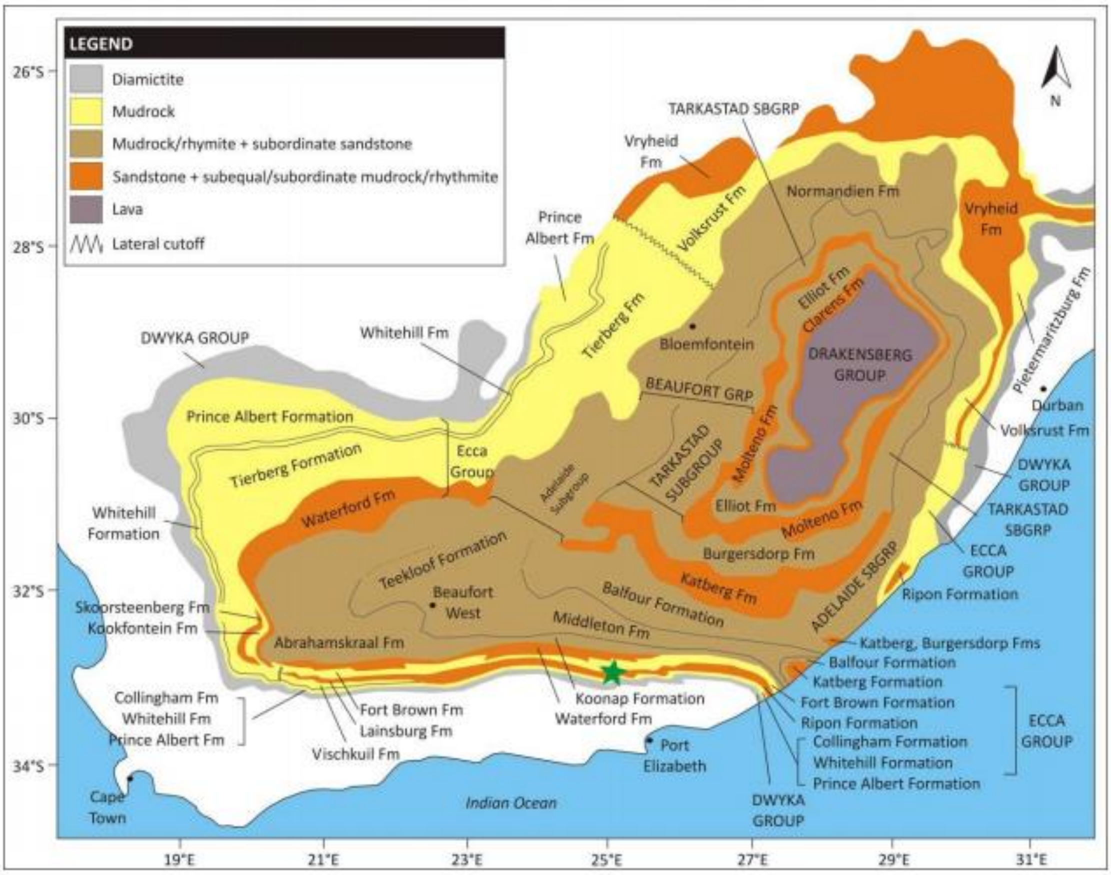

Figure 5: Geological map of the Main Karoo Basin.
Source: Catuneanu et al. (1998).

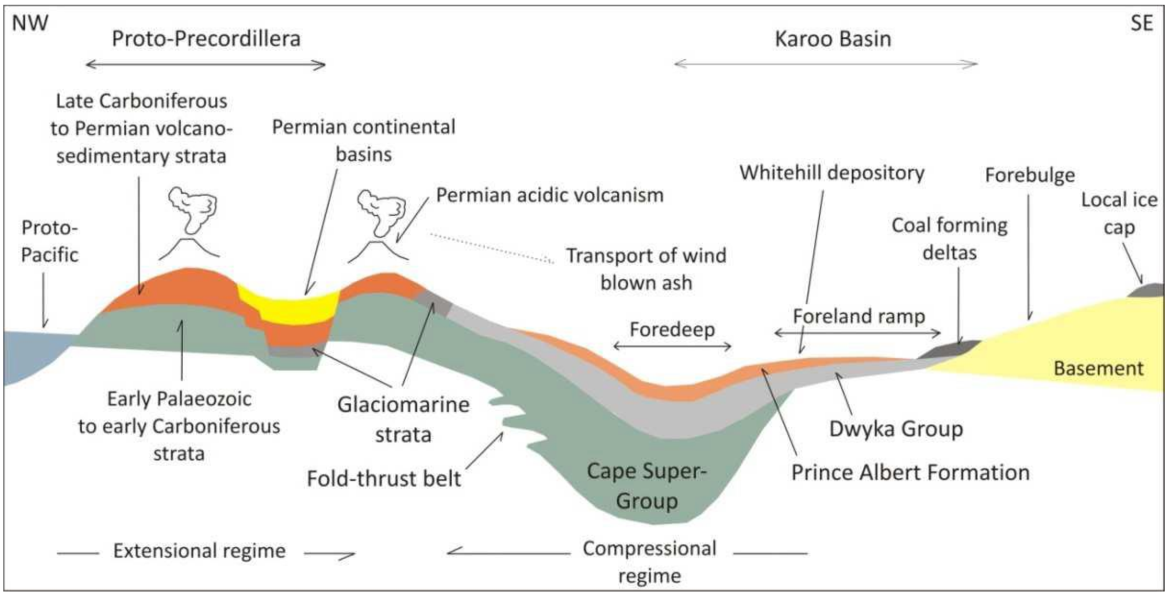

Figure 6: Schematic across the Cape Super Group and associated Magmatic arc.
Source: Visser (1992).

2.2.1 Stratigraphy of the Karoo Basin

The Ecca Group comprises of approximately 1300 m of marine siliciclastic sediments overlain by non-marine/ fluvial Beaufort Group (Fig. 7). The Ecca Group base comprises of the Prince Albert Formation (thickness of ca. 180 m). Prince Albert Formation is predominately made up of claystone and cherty claystone layers interbedded with carbonate rock. This is followed by the Whitehill Formation (thickness of about 30 m) composed predominately of carbonaceous claystone. (Flint et al., 2011). The Collingham Formation overlies the Whitehill Formation with a thickness between 30 – 70 m of dark carbonaceous claystone interbedded with layers of siliciclastic turbidites and volcanic ash. The upper section of the Ecca Group consists of the Vischkuil Formation, the Laingsburg Formation, the Fort Brown Formation, and the Waterford Formation. The stratigraphic package is approximately 1200 m, predominately of deep-water origin. The depositional sequence shows a depositional progression from a basin floor fan deposit to basin slope through fluvial and shallow dominated sediments (Johnson et al., 2006; Flint et al., 2011) (Fig 7 and Table 1).

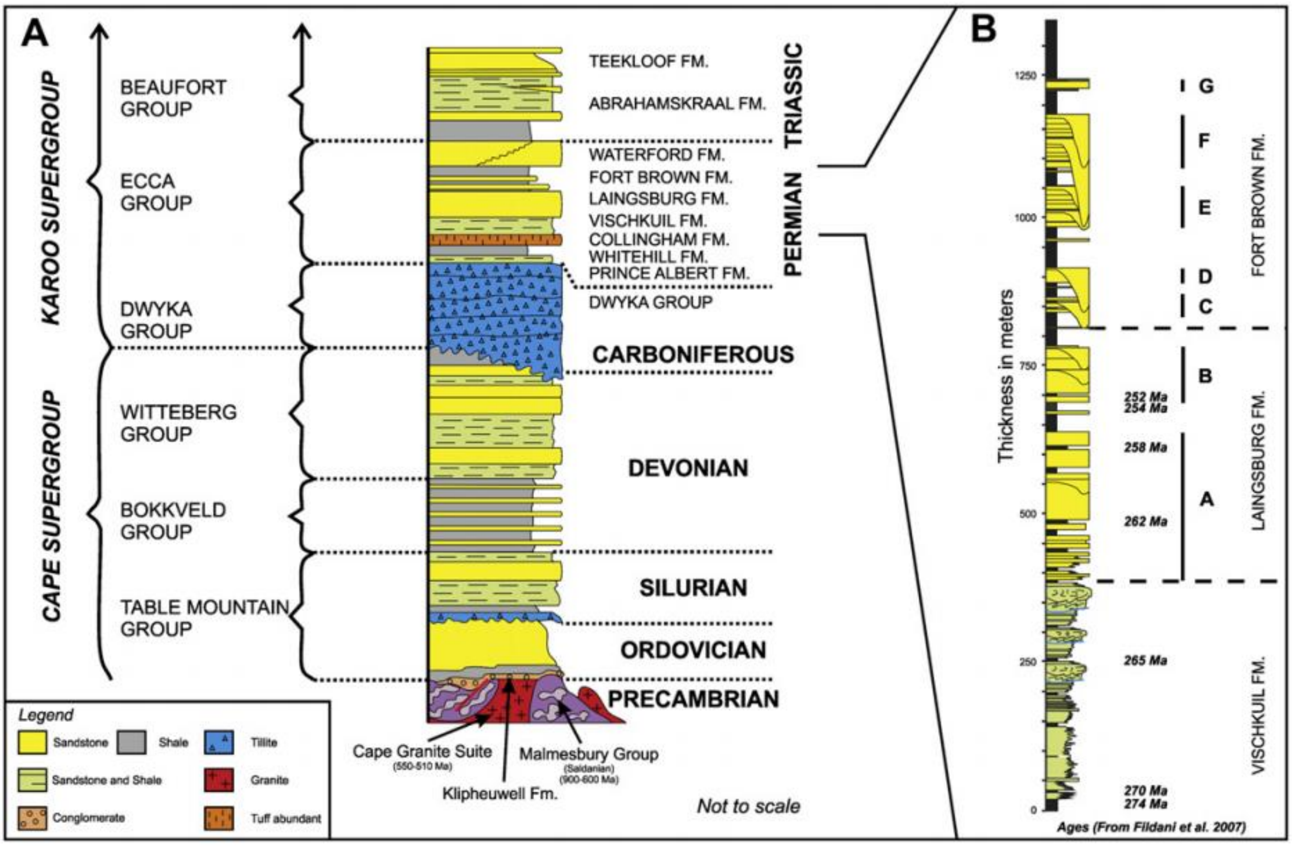

Figure 7: Lithostratigraphy of the Western Cape area.
Source: Flint et al. (2011).

Table 1: Lithostratigraphy of the Ecca Group.

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Notes: Modified from Baiyegunhi et al. (2017).

2.2.2 Gas Generation and Thermal History

Thermal maturity is a critical factor required for oil and gas generation; the prospectivity of the source rock begins as temperature and pressure increases with depth (Fig. 8). The organic matter transforms into different kerogen type expelling hydrocarbons at various stages of the petroleum generation process (Fig. 8). Facies variation has proven to affect the quality of thermal maturity of the source rock. Bacteria action on immature source rock at shallow depth generates biogenic gas at a temperature below 50°C. Bacteria action reduces significantly with deeper depth creating the conditions to generate the different hydrocarbons (McCarthy et al., 2011). Deeper burial of the source rock at 2 – 3 km generates thermogenic/natural gas at the gas window. The condensate production (a mixture of oil and gas) is likely to occur at this depth. The gas window ranges between 120 – 150°C with vitrinite reflectance between 1.2 to 2.0 % R_o. The process continues until the source rock becomes over-mature at a temperature of 200°C, vitrinite reflectance greater than 3.0 % (Fig. 8) (Roniwibowo et al., 2019).

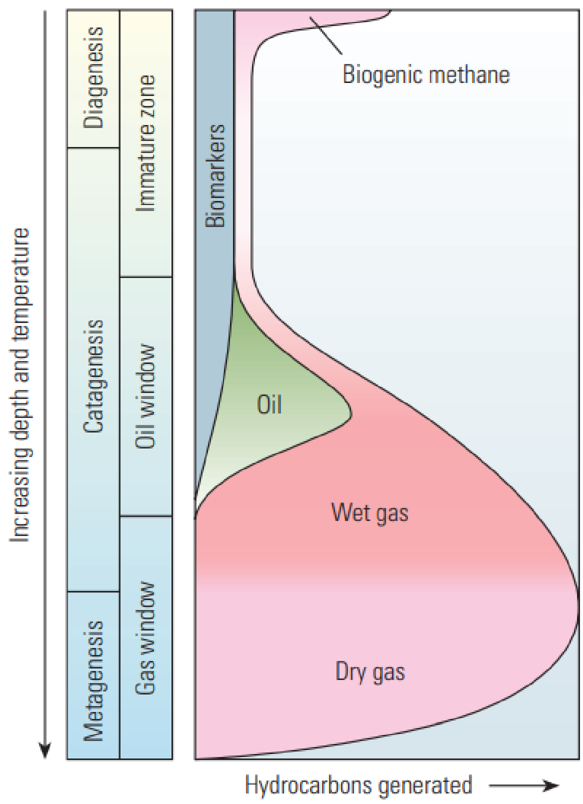

Figure 8: Diagram Showing Hydrocarbon Generation.

Source: McCarthy et al. (2011). Transformation of kerogen increases with depth, temperature, and pressure.

2.2.3 Petrophysical Characterization of the Shale Reservoir

Shale gas reservoirs are fine-grained and organic-rich sedimentary rocks. The Karoo shale reservoirs are composed predominately of clay minerals but may include fine-grained sandstones interbedded with mudstone, siltstones, calcite, and quartz (Baiyegunhi et al., 2017). The colour of the shale rock varies depending on the clay, organic content and the conditions prevailing at deposition. The shale serves as a source rock in conventional hydrocarbon settings and as both source and reservoir rock in unconventional oil and gas environments (Romero-Sarmiento et al., 2017).

With an increase in temperature and pressure, buried organic matter (plants and animals) are converted into lipids and transformed into kerogen. The kerogen is transformed into oil, wet and dry gas depending on the organic content. Given that shale rocks have poor porosity and permeability, the gas is trapped within the rock matrix as an adsorbed phase and may dissolve in water or oil (Glorioso and Rattia, 2012). Deng et al. (2014) stated that the adsorption of gas in shale gas reservoir is between 20–85 %, indicating the importance of adsorption for gas containment. An increase in the TOC and clay content has been found to increase the adsorption capacity of the shale reservoir. Shale reservoirs with low TOC and high clay content have been discovered to have a high adsorption capacity (Song et al., 2019).

Forecasting long-term hydrocarbon production from tight and shale reservoirs has been a critical challenge for geologist and reservoir engineers. Heller et al. (2014) investigated the matrix permeability and porosity of shale reservoirs using confining stress better to understand shale wells' flow regime and production profiles. The result suggested that shale reservoirs have intrinsically low permeabilities or nanopores requiring hydraulic fracturing to enhance the matrix properties of the reservoir. Regardless of their diagenetic and geographic origin, studies demonstrated that the permeability of shale reservoirs is < 0.1 MD and effective porosity <10 % (Ehrenberg and Nadeau, 2005; Boyer et al., 2006; Boyer et al., 2011; de Periere et al., 2011; Hatami et al., 2020). In addition, Kuila and Prasad (2013) demonstrated that the shale matrix has pores in the order of 2 nm to 50 nm in diameter. Field and drilling result showed that multi-stage fracturing of shale reservoir improved the estimated ultimate recovery (EUR) and rate of cumulative gas flows of the shale reservoir on the order of 30 % to 70 % (0.0005 md and 0.08 porosities, respectively) (Sunjay and Kothari, 2011; Tavassoli et al., 2013). Petro-physical evaluation of the Ecca Group demonstrated that porosity and brittleness of the Whitehill Formation would facilitate hydraulic fracturing of the rocks to produce gas.

2.2.4 Effect of Organic-Matter Type and Thermal Maturity

Total organic content refers to the weight or measure of the percentage of the total carbon (% weight) or the amount of TOC by weight per 100 g of rock (g TOC) (Mahmoud et al., 2017) (Table 2). The total organic matter and the matrix porosity are considered as the controlling factors for gas storage, kerogen type and character of the shale reservoir (Ross and Bustin, 2009). Studies have noted that thermal maturity alone is not enough to influence the generation and petroleum potential of the shale reservoir but a combination of factors such as depositional environment, mineralogical composition, and type of organic matter (Jarvie et al., 2007; Yang and Horsfield, 2020).

The black shales of the Lower Ecca Group are considered the prospective source rocks of the Karoo Basin (Chere, 2015). The organic-rich shales were affected by the loss of organic carbon from contact metamorphism and multiple intrusions of sills and dykes in the Early Jurassic (Aarnes et al., 2011). Analysis of core logs showed that the Whitehill Formation was not affected by the intrusion of sills and fall within the gas window for hydrocarbon generation. Chere (2015) found that the TOC of the Whitehill Formation ranged from 2.0%-7.3% R_o, (at

120ºC), making it a prospective focus for shale gas development/gas-bearing reservoir (Figs. 9a and 9b). Black (2015) and Euzen (2011) found that source rocks must have TOC greater than 0.5 wt % to be considered prospective. The reservoir must have good porosities to generate a significant volume of hydrocarbons.

The Whitehill Formation is predominately made up of dolomite. Dolomite is considered to have good porosity and a significant gas volume. Studies by Chere (2015) and Chere et al. (2017) noted that the Main Karoo Basin contained a mix of Type II and Type III kerogen. The Collingham and Whitehill Formations fall in the Kerogen II curve, while The Prince Albert Formation plot in the Kerogen III boundary. In terms of organic matter, Kerogen II is generated from phytoplanktonic organisms and Type III derived from the terrestrial deposit. Mineralogically, the Whitehill Formation is made up of feldspar 13%, illite 26%, quartz 35%, dolomite/ pyrite 23%. The presence of quartz indicates that the shale rock is brittle and 'frackable' (Table 2) (Chere, 2015).

Studies found that the lower Ecca Group falls within the high Tmax values identified as an over-matured and unprospective zone for shale gas development. The presence of phosphorus and barium indicates an extreme period of mineralization and paleo-activity during the depositional setting of the Ecca Group. In terms of depositional environment, Rimmer (2004) noted that the Whitehill Formation was deposited under an anoxic paleo-environment while the Prince Albert Formation was formed under euxinic conditions accumulation of marine and terrestrial organic matter (Table 3). The chromatographic breakdown gas extracted from Whitehill Formation displayed Carbon constituents ranging C1-C6 with toluene and benzene. The range of gases indicates that the organic content was over matured and reached an advanced phase of hydrocarbon generation, possibly from thermotectonic processes associated with the development of the Cape Orogeny (Chere et al., 2017).

Table 2 shows the relationship of TOC to resource potential; however, this is different for carbonate rocks based on the organic matter, structure, depositional environment, and composition of the source rocks.

Table 2: Total Organic Carbon vs. Resource Potential.

Total Organic Content Wt (%)	Resource Potential
< 0.5	Very Poor
0.5 – 1.0	Poor
1 – 2	Fair
2 – 4	Good
4 – 10	Very Good
> 10	Excellent

Source: Black (2015).

Table 3: Classification of Kerogen Type based on Depositional Environment.

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Note: Modified from Flint et al. (2011) & Baiyegunhi et al. (2018).

The Krevelen model is used to characterize the source rocks and estimate the kerogen's quality on a plot of O/C vs. H/C (Figs. 9a and 9b). Table 4 shows the different kerogen types, depositional environment, and hydrocarbon potential. Kerogen I is oil-prone, constituting of high H/C and low O/C ratios predominately of algal organic matter, while Kerogen III has the highest GOR and generates more hydrocarbon gas than Kerogen I, II and IV. Kerogen II are considered as oil and gas prone with intermediate H/C and O/C ratios containing a mixed content of plants and terrestrial input. Type III kerogens have higher O/C and lower H/C ratios composed of humid and terrestrial contents (Flint et al., 2011; Baiyegunhi et al., 2018).

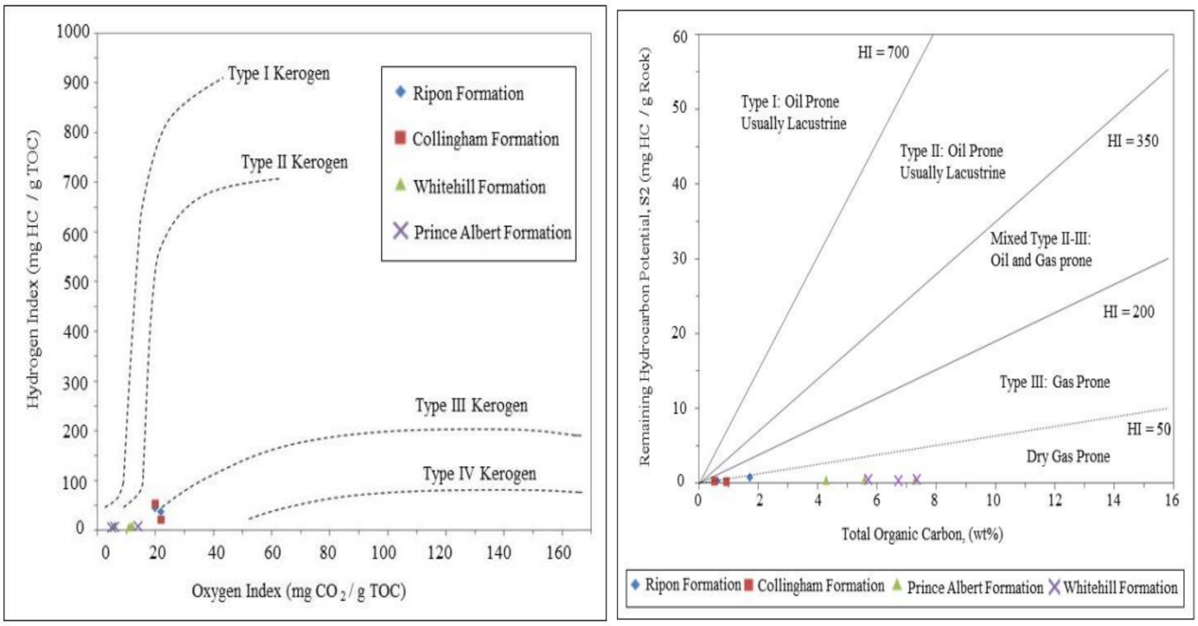

Figure 9a:van Krevelen showing Hydrogen index (HI) Figure 9b: van Krevelen diagram showing Kerogen Types Oxygen Index (OI)

Notes: All samples of the Whitehill Formation plot in the Kerogen III with a mixture of II. The organic content are predominantly overmatured. Sources: Baiyegunhi et al. (2018).

2.2.5 Resource Potential of Shale Gas in the Karoo Basin

The Karoo Basin is a frontier basin with limited drilling and seismic data. Preliminary analyses of the limited subsurface data of the Cranemere 1/68 well (drilled by the Southern Oil Exploration Corporation – SOEKOR) in the 1960s coupled with surface outcrop data indicate the existence of a gas prone geological province (Chere et al., 2017; Nolte et al., 2019). These early gas discoveries appeared to be an opportunity and upside potential for shale gas exploration. Production test carried out in the Cranemere 1/68 well indicated that gas flowed from the well at the rate of 1.8 million cubic feet/ day (Mowzer, 2012; Vermeulen, 2012; Chere et al., 2017; Nolte et al., 2019). The success of shale gas development is dependent on a better understanding of the geological uncertainties, given that large sections of the Karoo basin are underexplored.

Studies have shown that the Ecca shales provide the source rocks for the Karoo Basin (Chere, 2015; Chere et al., 2017). The Ecca shales were subjected to episodes of tectonic activities during the deposition of the sediments; the intrusion of dolerites could have resulted in the release of gas from the basin (Brunner and Smosna, 2011; Vermeulen, 2012). Chere (2015) noted that the Whitehill Formation compares favourably with the prospectivity of the Marcellus and Barnett shales in the US. Besides, the average TOC values across the Whitehill shale is consistent with the Marcellus and Barnett Shales (Table 4).

Studies have shown that the Karoo succession/ Supergroup was penetrated during the early Jurassic period with numerous dolerite dykes and sills. The Karoo succession is mainly covered with dolerite sills with individual sill up to 150m in diameter (Svensen et al., 2007). Structurally, the dykes generally occur in a parallel orientation, trending towards the northern margin of the Cape Fold Belt, becoming variably deformed and intrude progressively at greater depth within the central Karoo Supergroup, further complicating the geology of the Karoo basin (Linol et al., 2016). The Karoo basin represents the only example of shale play in the world, with abundant dykes and sills raising uncertainties about the commercial potential of the basin to produce gas.

Table 4: Comparison of Hydrocarbon Prospectivity between the Barnett, Marcellus, and Whitehill Shales.

Table removed for copyright reasons

Modified from Geel (2013) & Baiyegunhi et al. (2018).

2.2.6 Trapping Mechanism of Gas in the Karoo Basin

Different analogues have been drawn to compare the trapping mechanism between the gas-bearing shales in the Karoo basin with shales plays around the world (Svensen et al., 2007; Pietersen et al., 2021). The effects of the dykes in the Karoo basin are intensely debated. However, a widely held perspective suggests that heating from magmatic activities during the Early Jurassic had a significant impact on the TOCs and vitrinite reflectance of the shales (Fig.10) (Svensen et al., 2007).

The Karoo basin is situated as a geological structure initiated by intrusive volcanic activity and contact metamorphism (Fig. 11). The foreland portion of the Karoo basin is thick (8km) stacked of thick Carboniferous to Early Jurassic sediments (Jamtveit et al., 2004). Large volumes of intrusive magmatic dykes and sills penetrated the Karoo Basin in the Early Jurassic, heating the organic-rich shales of the Whitehill and Prince Albert Formation of the Ecca Group. The structures were intruded by planar sills of up to 120 m thick (Fig. 11). The reaction of the heated sills created metamorphic aureoles and the expulsion of pore fluids and gases, including the formation of hydrothermal vents in the Karoo Basin. A remarkably features that cut through the basin, contact metamorphic aureoles, and sills is the exposure of numerous breccia pipes covered with brecciated and metamorphic/ cooked shales of thickness up to 150 m outcropped in a large area of the Karoo basin (Fig. 10) (Berner, 2002; Svensen et al., 2007).

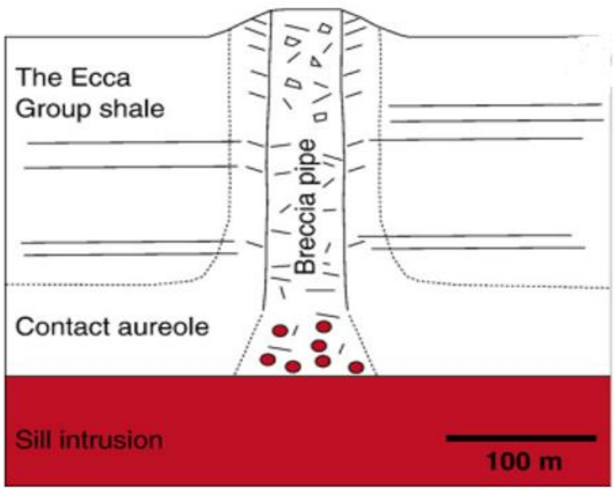

Figure 10: Schematic showing sill, contact metamorphic aureole, and breccia pipe.

Source: Svensen et al. (2007).

Notes: The red spots in the contact metamorphic aureole represents sediment-dolerite interactions.

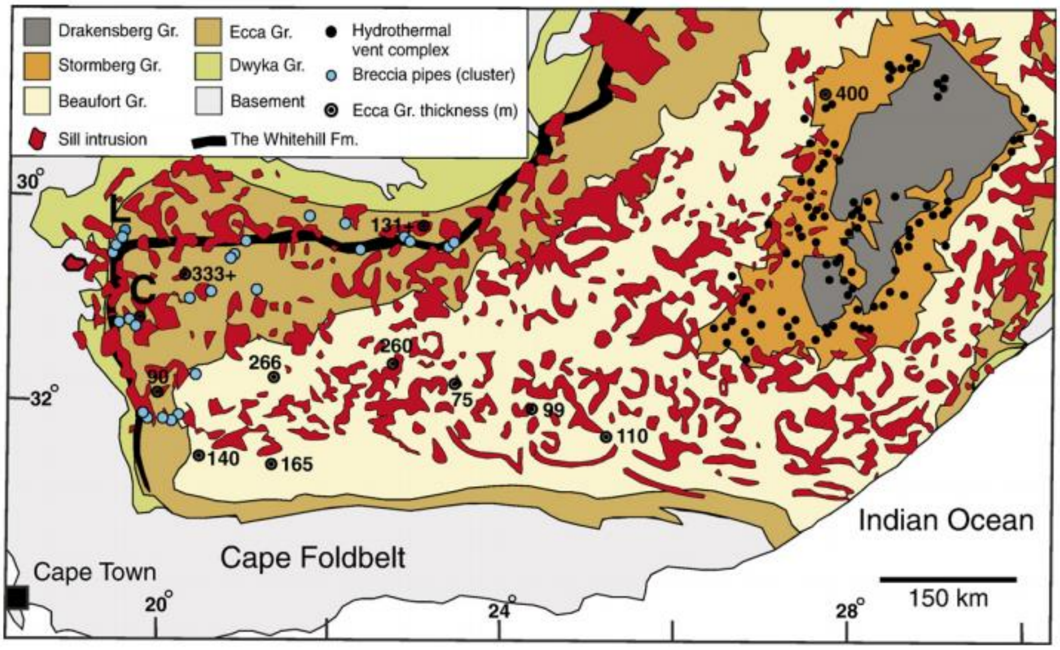

Figure 11. Dissemination of hydrothermal vent complexes and breccia pipes in the Karoo Basin.

Source: Svensen et al. (2007).

Notes: Approximately 390,000 km^2 of dolerite intrusions and breccia pipes emplaced to the Ecca and Beaufort groups. The symbol for the breccia pipes corresponds to pipe clusters.

2.3 Stages of Shale Gas Development

The life cycle of shale gas development is illustrated in Figure 12; the design of the well depends on the well objective and prevailing geological conditions of the basin (King and King, 2013; Huddlestone-Holmes et al., 2017). A summary of the various stages is illustrated below (Fig. 12):

Figure removed for copyright reasons

Notes: Modified from Huddlestone-Holmes et al. (2017) & Khalifeh and Saasen (2020).

2.3.1 Basis of Design Phase

The basis of design sets the engineering requirements of the well, including commissioning, site construction, and conditions to fulfil the well objectives. In addition, the basis of well design integrates the lessons learnt from historical data into the drilling program. The design of the well evolves across the development of the geological field. The design of the well incorporates a comprehensive analysis of the geology, including safety requirements for the casing, cementing, formation logging and testing objectives (Aird, 2018; Rackley, 2017; Khalifeh and Saasen, 2020).

2.3.2 Construction Phase

This phase involves constructing the site and the mobilization of rig services and equipment. This involves aggregating all the equipment's including pipes and chemicals (additives) at the rig site. The road networks and facilitates are constructed for waste disposal, storage tanks and pipelines (Huddlestone-Holmes et al., 2017). Up to 8 wells spaced at 300 m intervals can be drilled from a single well pad, enhancing the overall productivity of the field, thereby reducing the footprint occupied by the drilling rig (Fig. 13) (Edwards et al., 2011; Soeder 2018).

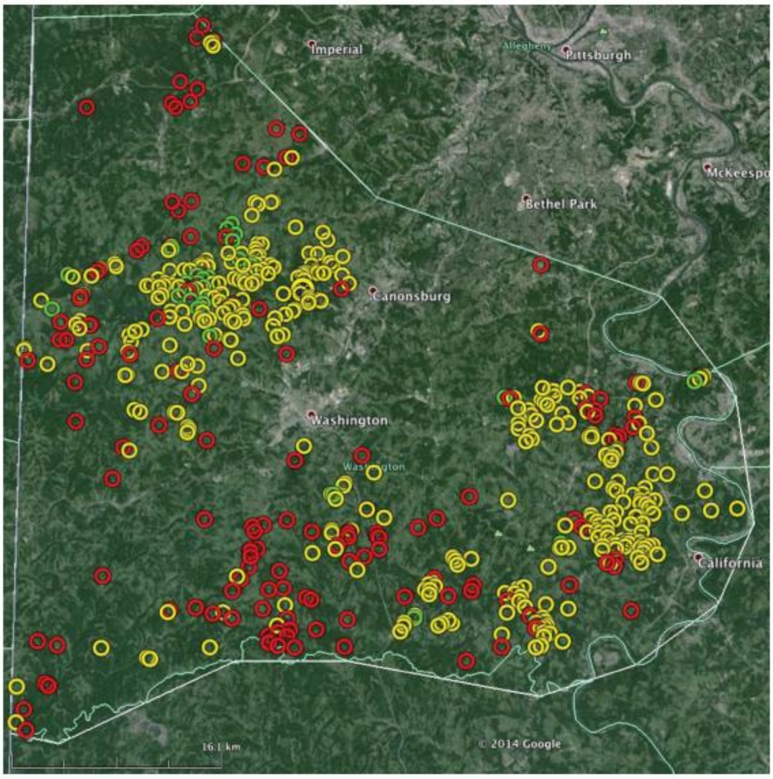

Figure 13: Shale Gas Development in Washington County, Western Pennsylvania (2005 - 2013).
Source: Lampe and Stolz (2015).
Notes: Yellow circles, well operations (e.g., pad position) installed between 2005 and 2010 (351), red circles, well

operations installed since 2010 (134), green circles, sites restored since 2010 (44). Source: Lampe and Stolz (2015).

2.3.3 Operational Phase

The operational phase focuses on the drilling, hydraulic fracking, and completion of the well according to design (Fig. 14). The operational phase also deals with managing the safety of the well and issues related to barrier/ wellbore integrity. All surface equipment related to the integrity of the well is tested to verify that the equipment can effectively withstand downhole conditions and optimal gas production. Formation logging and hydraulic fracturing are initiated in the operational phase to produce the hydrocarbons (Huddlestone-Holmes et al., 2017; Khalifeh and Saasen, 2020).

Hydraulic fracturing, or ‘’fracking,’’ is a well engineering technique involving the injection of fluids (10,000–20,000 m^3) composed of water, chemicals, and sand under high pressure into a target formation to induce the formation and increase the connectivity of existing rock fractures. Hydraulic fracturing is typically used in unconventional reservoirs and low permeability rocks such as shale, tight sandstone, and coal beds to enhance the flow of hydrocarbons to the wellbore (Kissinger et al., 2013).

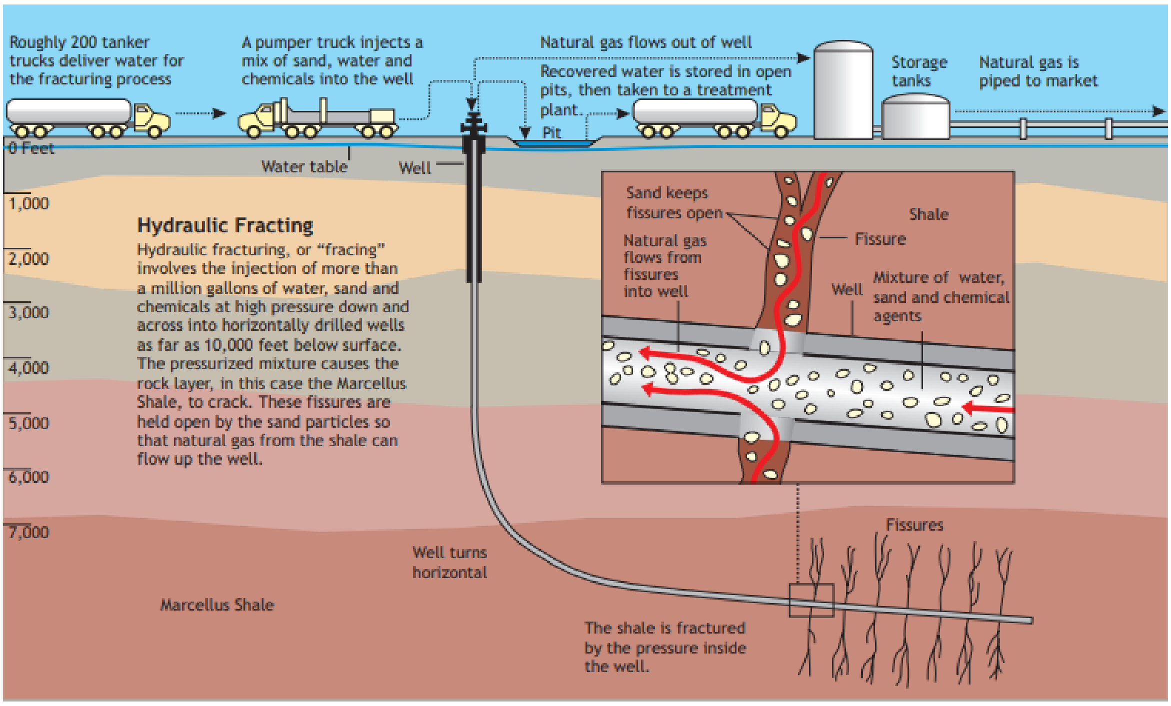

Figure 14: Schematic of Hydraulic Fracturing

Source: Sutter et al. (2015).

Figure 14 depicts a schematic construction of a typical shale gas well. The borehole traverse three sections of the formation: a potential shallow aquifer zone, an intermediate zone with different permeabilities and porosities containing formation fluids and deeper gas strata, or a horizontal zone marked for hydraulic fracturing and gas production.

The fracturing of shale rocks is carried out over multiple stages and the production target of the well (Fig. 15). The multiple staged approach allows a specific zone to be fractured and produced, performed over 1–2 km horizontally, typically at 85° tangentially (Khalifeh and Saasen, 2020). Horizontal drilling allows a large reservoir area to be intersected for oil and gas production. Horizontal drilling also enables the operator to drill and penetrate the lateral extent of adjacent formation targets, thereby reducing the footprint of the operations. As discussed, the typical spacing of the fracturing stages ranges between 15–30 m clusters, spaced at 300 m (Kissinger et al., 2013). Mechanical plugs isolate the clusters to be fractured before an injection is initiated to the breakdown pressure of the rock. The direction of the induced fractures depends on the orientation of the in-situ stress regime, with fracture growth occurring perpendicular to the principal minimal stress (Fig. 15) (Krietsch et al., 2019).

The overburden stress at deeper depth is greater than the horizontal stress indicating that the induced fractures are vertically orientated. Further propagation of the fractures is controlled by adjusting the surface pressure and fluid flow into the wellbore. Some of the fluid is lost into the formation during the hydraulic fracturing process. At this stage, proppant is added to the fracking fluid and injected downhole to keep the fractures open to hydrocarbon production (Fink, 2020).

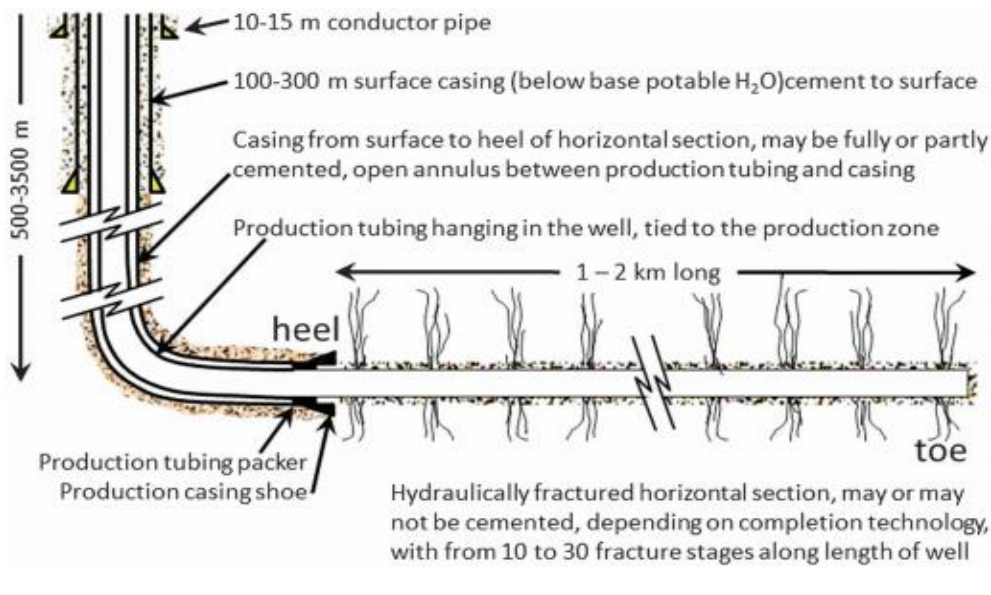

Figure 15: Schematic of Multistage Hydraulic Fracturing Operation (not to scale).
Source: Dusseault and Jackson (2014).

The final stage involves flushing the wellbore to remove sludge and debris as flow back so gas can flow into the wellbore and accumulate in surface storage tanks. Studies have highlighted that the amount of drilling or fracturing fluid recovered after hydraulic fracturing operation ranges from 10–30 %. Fluid loss at the surface or into the formation is routinely observed (Fig.16) (Olsson et al., 2013).

The volume of water used for fracturing ranged from 3–5 million gallons. Further studies noted that an average of 300,000 lbs of proppants is used for fracking a typical shale well (Beckwith, 2011; Lampe and Stolz, 2015). Depending on the depth and length of the target formation, an average shale well generates approximately 1,000 tons of cuttings. The flowback and produced waters are stored on surface tanks and have been found to contain dissolved solids, halides, organics and naturally occurring radioactive compounds. At this point, the produced water is either treated and used for subsequent hydraulic fracturing operations or injected in disposal wells. Where permitted, wastewater is disposed of in open impoundments and may constitute a potential pathway for surface contamination (Hayes et al., 2012; Freedman, 2014).

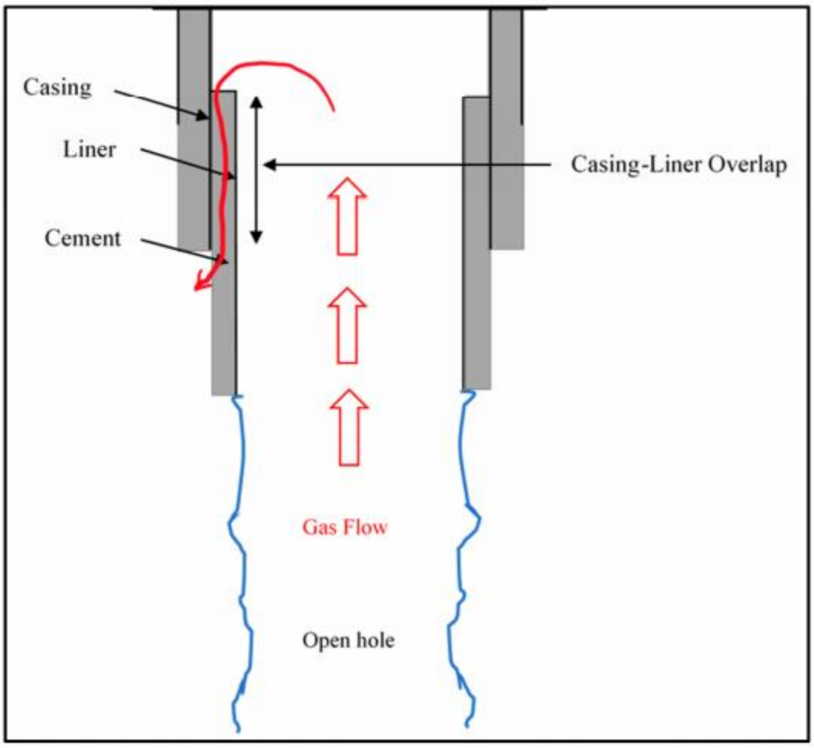

Figure 16: Schematic of Casing Types and Gas Migration
Source: Al Ramadan et al. (2019).
Notes: Through the Casing and Cement within the Casing–Liner Overlap.

2.3.4 Intervention Phase

This phase is used to manage issues related to well integrity such as ‘’kicks’’ including all operational and equipment failures that can result in ‘’lost time incidence’’. In some instance, re-entry of the well is initiated to maintain the integrity and safety of the well that will stimulate secondary production and recovery of hydrocarbons. The decision for well intervention and clean-up operations is balanced against the economic cost of the well and the need for workover operations (Khalifeh and Saasen, 2020).

2.3.5 Decommissioning Phase

The decommissioning phase is a process employed to safely abandon the well at the end of production life where the well is no longer economical to maintain. The production tubing is retrieved, and the well plugged and abandoned by injecting cement slurry downhole to the ‘’bullhead’’ the reservoir. The process involves removing hazardous substances and equipment so that the structure no longer poses any risk to the environment or public health in the immediate and future. The site is remediated and restored to its original state (Moeinikia et al., 2015; Khalifeh and Saasen, 2020).

2.4 Barrier Failures in Shale Gas Wells

The importance of well integrity and the safeguard of shallow groundwater has been highlighted in several studies (Davies et al., 2014; Lehmann and Totsche, 2020; Lackey et al., 2021; Milton-Thompson et al., 2021). Effective wellbore integrity inhibits methane and harmful anthropogenic gases/ pollutants into the atmosphere. This is critical as methane is considered a more heat-trapping gas than CO_2 (Davies et al., 2014). Faulty wellbore conditions create severe engineering and well completion challenges, leading to the uncontrollable flow of drilling fluids or gas to unintended zones resulting in shallow aquifer contamination and release of fugitive gas emissions. This can lead to grave health, and safety conditions in severe cases refer to as ‘Kicks’ and blowout. Impacts could result in spills and seepage at the surface ecosystem (Davies et al., 2014; Kiran et al., 2017).

Well integrity failures cover all aspect of mechanical, chemical, and operational defects (Davies et al., 2014). Past studies suggest that well integrity barriers involving steel casing, downhole tools and packers are impacted by mechanical processes, steel corrosion and cement carbonation (Fig.17) (Al Ramadan et al., 2019). The cement slurry is used to seal the flow of fluid from the wellbore to the formation. However, the efficiency of the cement bond and the stress geometry of the wellbore is dependent on the chemical composition of the cement additives and the in-situ geological conditions. The corrosion of steel casing from acidic sources, from H_2S and CO_2 gases, have also been found to degrade the integrity of the casing (Nath et al., 2018).

Studies have argued that variation in pressure and temperature conditions induces stress on the primary and secondary well barrier leading to barrier failure. Operational inefficiencies and poor drilling practices also play a crucial role in exacerbating well integrity failures (Patel et al., 2019). Al Ramadan et al. (2019) argued that the migration of gas, water and fines into the wellbore constitute crucial issues in compromising wellbore integrity. Barrier failure can occur at any phase of the well's life cycle. The main factor responsible for the loss of drilling rigs is shallow flow/ ‘’kicks” and blowout at the surface (Fig. 17) (Aggelen, 2016).

Studies have indicated that gas may migrate through channels created by hydraulic fracturing to the wellbore (Davies et al., 2014). High pressure is induced in the wellbore during hydraulic fracturing, which can enlarge the channels allowing fluids or gas to breach the casing/ seal between the formation and shallow aquifers. Huddlestone-Holmes et al. (2017) reported casing failure during hydraulic fracturing operations in the Baldwin 2HST-1 well; however, the well was contained by secondary casing strings.

Davies et al. (2014) argued that approximately 4 million oil and gas wells have been drilled onshore globally and reported a variable number of barrier failure among the wells (both conventional and unconventional) examined. The authors noted that 6.3% of the wells drilled in the Marcellus between 2005 and 2013 have issues related to integrity failure. One out of every 143 wells drilled at the end of 2000 in the UK experienced some form of barrier/ integrity failure. Figure 17 shows a breakdown of wellbore integrity failures conducted by Vignes and Aadnoy (2010). Out of the 406 wells examined, 18 % had well/ mechanical barrier failure, 11 % of the wells had cement related issues, while 39 % had a variety of tubing failure. A study carried out by the Norwegian Petroleum Safety Authority of 1677 wells on the continental shelf of Norway in 2008 showed that 24% of the wells experienced barrier failure. In a similar study carried out in 2009, 24 % of 1712 wells had barrier failures. 26 % of 1741 wells examined in 2010 experienced barrier failure. This has raised questions concerning possible risks to groundwater contamination given that shallower strata may contain water to support the local ecosystems (Davies et al., 2014). It is a standard practice to seal or case wells passing through permeable or water-bearing layers (King and King, 2013). The best practice ensures that multiple and independent well barrier are installed to mitigate potential failure and leakage of fluids. Continuous monitoring and evaluation using testing and logging capabilities must alleviate well integrity failure (Kiran et al., 2017).

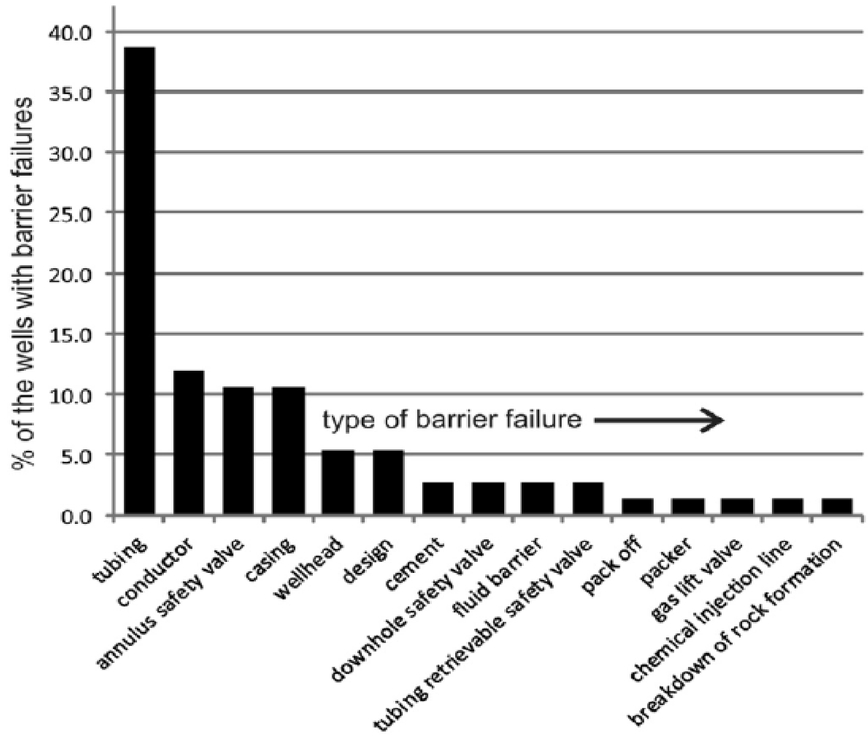

Figure 17: Causes of Integrity failures in Oil and Gas wells.

Source: Davies et al. (2014).

Notes: Potential barrier failure can occur for several reasons: deterioration of casing and cement job, poor well completion performance resulting in boreholes becoming vulnerable and conduit for cross flows between drilling and formation fluid.

2.5 Potential Contaminant Pathways

Boreholes drilled for shale gas development penetrates through shallower strata that may contain groundwater that supports human activities and the local ecosystem before reaching the target zone. It is a standard practice to safeguard the aquifer by steel casing; however, such strata remain a potential source of subsurface groundwater contamination (King and King, 2013). Possible contamination can occur over various reasons, including deterioration of the cement, corrosion of the casing and poor completion practices. In such conditions, boreholes become potential conducts and source for cross-contamination. Vertical pressure gradients can result in fluid migration along possible flow paths. Surface and groundwater contamination may occur at any phase of the hydraulic fracturing process if fracking chemicals and deep formation fluids migrate to shallow water-bearing bodies, streams, and river systems (Fig.18). Conceptually, the migration channels and faults are the potential intersection and connection of reservoir fluids to the overlying aquifer. A broken seal between the wellbore and the casing can also provide possible pathways for crossflow to occur (Bishop et al., 2020; Pan and Oldenburg, 2020). Figure 18 illustrates the potential path for contamination.

Typically, organic-rich shale resources are buried at depths (>1500 m) deeper than most formation bearing waters. It is unlikely that fractures propagation by hydraulic fracturing activities will grow or extend into shallow groundwater sources (Rutqvist et al., 2015). Myers (2012) found that the time taken for the fluid to migrate from the fractured shale via fault zone takes about ten years. The migration of fluids travelled vertically rather than horizontally, reflecting the direction of the in-situ principal stress orientation of the shales. The pressure from hydraulic fracturing activities decreases exponentially with distance from the wellhead within a radius of 300 m (Huddlestone-Holmes et al., 2017). The risk to aquifers and surrounding areas is likely to increase given the growth of shale gas development. Dusseault and Jackson (2014) noted that fluid and natural gas migration to shallower water strata is increased dramatically in suspended/ abandoned wells. Flewelling and Sharma (2014) explored the barriers to vertical fluid flow and concluded that the time scale required for upward migration of fracturing chemicals will be significantly long given that the permeability of the shale resource is low; therefore, flow rates will be significantly low. The most likely source of contamination is through micro annulus delamination of the wellbore (Fig. 18).

Gassiat et al. (2013) demonstrated that hydraulic fracturing should be prevented in areas with conductive major faults zones, fluids should be monitored for potential underground water contamination. In addition, Flewelling et al. (2013) noted that the models used to predict fluid migration are unreliable because they have not been validated against prevailing petrophysical conditions. Kissinger et al. (2013) found that potential methane leaks to shallow bedrock can occur between permeable fault zone and overburden with low gas saturation of 1%. Engelder et al. (2014) analysed cuttings and core samples from the Marcellus and Haynesville gas shales and found evidence of aquifer contamination resulting from fault propagation initiated by hydraulic fracturing activities. Birdsell et al. (2015) developed a numerical transport simulation technique to model the volume of fluids that could migrate to the water-bearing formation. The authors observed that the likelihood of induced fracture to transmit fluid to the overlying aquifer is significantly low, especially for deep shale formations, compared to the time required for the fluids to travel from shallow shale resource to near-surface aquifers.

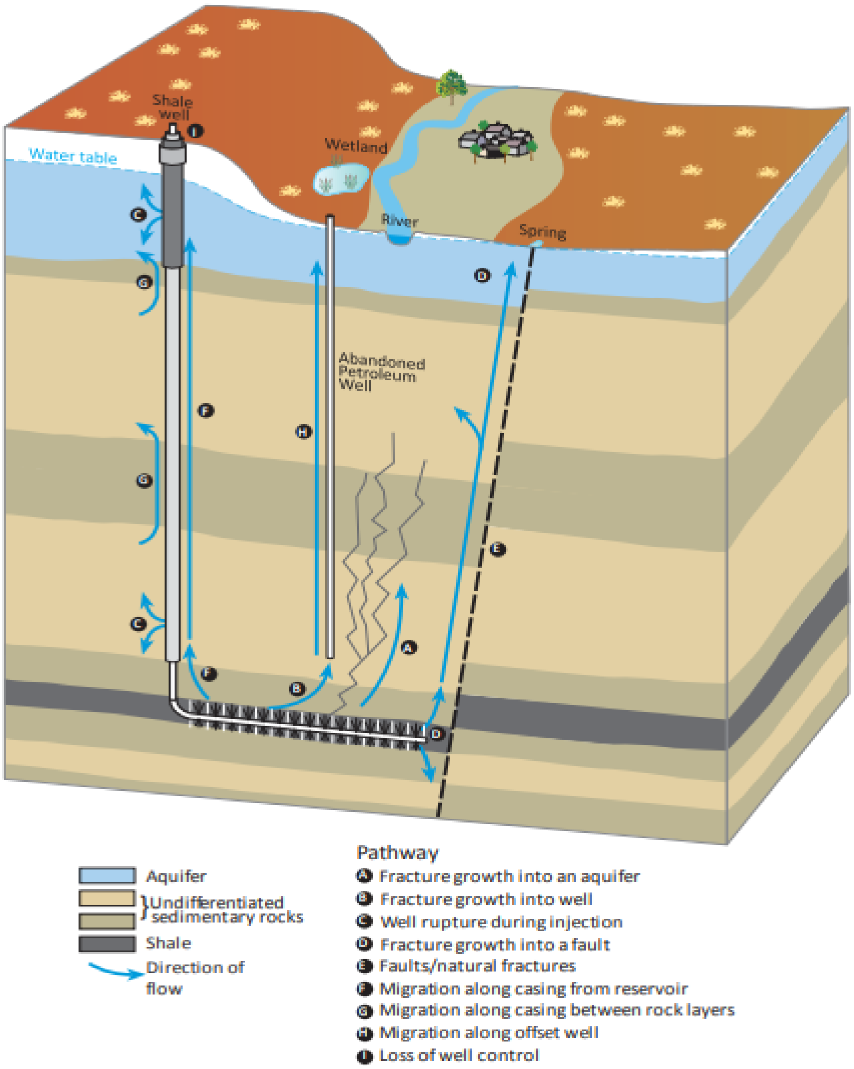

Figure 18: Schematic Showing Potential Pathways of Contamination from Hydraulic Fracturing.

Source: Huddlestone-Holmes et al. (2017).

2.6 Resource Requirement

Table 5 provides a summary of the resource requirements for shale gas development. The resource requirements were described in detail by Hardy (2014) and include activities such as water requirement, waste and cuttings generated in the life cycle of the shale well and the area extent of the pads. Hardy (2014) highlighted the scenarios and methodology assessed the range of potential impacts on water resources and waste disposal per well and modelled after shale development in the US and Canada (Table 5).

Table 5: Summary of Resources, Pre and Post-Production.

	Activity	Six well pads drilled vertically to 2000 m and laterally to 1200 m: Low	High
Construction	Well pad area (ha)	1.5	2
Drilling	Wells	6	-
	Cuttings volume (m^3)	827	-
Hydraulic Fracturing	Water volume (m^3)	54,000	174,000
	Flowback fluid volume (m^3)	7920	137,280
Surface Activity	The total duration of surface activities pre-production (days)	500	1500
	Total truck visits	4315	6590
Re-fracturing Process Assuming an average of 50% of wells re-fractured only once	Water volume (m^3)	27,000	87,000
	Fracturing chemicals volume, @ 2% (m^3)	540	1740
	Flowback fluid volume (m^3)	3960	68,640
	The total duration of surface activities for re-fracturing (days)	200	490
	Total truck visits for re-fracturing	2010	2975
Total for 50% re-fracturing	Well pad area (ha)	1.5	2
	Wells	6	-
	Cuttings volume (m^3)	827	-
	Water volume (m^3)	81,000	261,000
	Fracturing chemicals volume, @ 2% (m^3)	1620	5220
	Flowback fluid volume (m^3)	11,880	205,920
	The total duration of surface activities pre-production (days)	700	1990
	Total truck visits	6325	9565

Source: Hardy (2014).

2.7 Conclusion

The Karoo Basin is considered an active petroleum system based on the exploration results of well CR1/68 drilled in 1968. The CR1/68 flowed gas at 1.83 mmscf/day for 23 hours. The Ecca Supergroup in the central Karoo basin is considered the target for shale gas development. The Permian Whitehill Formation within the Ecca group is thought to be the most prospective for shale gas development owing to the high TOCs of about 5 %, an average thickness of 30m, optimal maturities of R_o = 1- 4 %, stratigraphic depth >1500m with extensive regional continuity. The underlying Prince Albert and Collingham Formations are also considered of economic interest given the proximity of the Formations to the Whitehill. In 2010, the government awarded exploration licenses to Falcon Oil and Gas, Shell B.V. International, Sasol-Chesapeake-Statoil consortium and Bundu Oil and Gas (Pty) Ltd commence desktop studies in the Karoo Basin. The government imposed a moratorium to stop further exploration activities.

The Gas initially in place (GIIP) remains highly uncertain due to dolerite intrusions. Studies have shown that the dolerites may have compartmentalized or metamorphosed/ overcooked the shales to over maturity. Some studies have demonstrated the volume of gas in place between 30 to 485 Tcf. Although the moratorium remains in place, the Basin's potential remains inconclusive until drilling and actual well test conducted to determine the gas in place.

Chapter 3: The Environmental Impacts of Shale Gas Development

3.1 Introduction

Shale gas development presents a promising alternative to conventional fossil-based energy sources (primarily coal and crude oil); however, the sustainable development of shale gas development may require significant environmental trade-offs (Heffron et al., 2018). The literature review highlights the potential environmental impacts of shale gas development. Literature has highlighted a plethora of attributes and benefits associated with shale gas development which form the basis for promoting the value of the shale technology (Jenner and Lamadrid, 2013). Current environmental and policy mechanisms have evolved rapidly to facilitate and support the adoption of shale gas as a transition energy. The growth of the shale industry is hinged on exposure pathways and potential impact on the environment and human health. This study highlights what is currently identified as the limitations, toxicity, exposure, and data gaps concerning the environmental impacts of shale gas development. The exposure pathways provide an analytical setting to explore the relationships between pollutant sources and impact outcomes. The pollutant source begins with emissions and venting of contaminants into the atmosphere, underground and surface water bodies, and soil. The level of concentrations of contaminants in the atmosphere and surrounding environments from these emissions determine the magnitude of human and ecological exposures (Small et al., 2014).

Hydraulic fracturing fluids migrates through the subsurface strata and surface bodies exposed through a number of pathways including surface spills, leaks from surface tanks, compromise in well integrity, accidents during waste transportation, well pad, kicks, blowouts, storm runoff from flooding events. Chemical compounds in the fracturing fluids may pose significant risks to public health and the environment (Rozell and Reaven 2012). Many of the compounds used in the fracturing fluids have been found to be hazardous and are strictly regulated in other industries (Colborn et al. 2011; Aminto and Olson 2012). Colborn et al. (2011) noted that some of the chemicals lack scientifically and empirical based contaminant levels making it difficult to measure their level of impact on the environment and public health. Moreover, uncertainty about the levels of concentrations and impacts continue because of the limitations on required chemical disclosures by energy and environmental policy laws (Centner 2013; Maule et al. 2013; Konschnik et al. 2013; Centner and O'Connell 2014).

Given the limitations on trade secret and the lack of disclosure by energy companies, energy researchers and environmentalist acquire information on the chemical composition of fracturing fluids from MSDS. More so, chemical hazard evaluation studies carried out by Colborn et al. (2011) on fracturing products represent one of the assessments of the compounds used in fracturing fluids. Studies by Colborn et al. (2011) failed to quantify dose, exposure, and impact of fracturing chemicals across population. However, subsequent studies have identified and classified the compounds into 12 impact categories (Vandenberg et al. 2012; Zoeller et al. 2012).

This chapter explored the overall approach in addressing the environmental concerns of shale gas development in South Africa. The challenges of developing the Karoo shale resource will continue to be a central focus on sustainability goals. If shale gas development is viewed as contributing to environmental protection and viable energy development, it seems plausible that public support will accelerate and approve the transition to long-term sustainable energy development.

3.2 Policy Position to Promote Shale Gas in South Africa

The Karoo Basin is considered to have an economic deposit of shale resource that could be used to diversify South Africa's energy mix and support the transition to a green economy (US EIA and Kuuskraa, 2011; Scholes et al., 2016). South Africa is currently the highest emitter of GHG in Africa and the 13th in the World (US EIA, 2013). The effects of domestic wood burning, and charcoal production remains a challenging issue to environmental conservation and contribution to the emission of GHGs in Africa (Orindi and Murray, 2005; May-Tobin, 2011). Bush burning can undermine long-term adaptation strategies and increase vulnerability to climate change in poor communities in South Africa (Chidumayo and Gumbo, 2013). Empirical data published by Frumhoff et al. (2015) and Taylor and Watts (2019) suggest that more than half of global GHGs emissions originate from the 'big fossil fuel' investor-owned companies. While industrial cities are responsible for significant emissions, indigenous communities bear the environmental and human impacts (Scorgie et al., 2004; Pauw et al., 2008; Heede, 2014).

Given the implications of GHG on South Africa, sustainability development formed the basis for the shift from fossil fuel consumption to environmentally friendly energy systems (i.e., consistent with limiting the 2°C global temperature target) (Heede, 2014; Frumhoff et al., 2015; Grigoryev and Medzhidova, 2020). The South Africa energy policy option including a combination of solutions ranging from reduction in standing wood biomass, switch from coal-powered energy base to low carbon energy, focus on behavioural change in energy utilization and significant investment and acceleration of sustainable energy development (i.e., developing the Karoo shale resource and renewable energies) (Kiratu, 2010; Schmidt et al., 2017).

The South Africa Air Quality Act (2004) sets the framework of air quality and emission controls and robust strategies to improve air quality in South Africa. The National Environmental Management Air Quality Act, 2015 established the legal standards for emissions control for electricity generation and enforcement of low sulphur fuels from vehicles comparable to EURO 5 emission environmental standards (Myllyvirta, 2014). The country's long-term decarbonization plan prioritises energy pathways that prevent the carbon ‘lock in’, reducing emissions by 42 % by 2025 and achieving an optimal increase of 14% renewable energy by 2030 (Kiratu, 2010; Merven et al., 2014; DOE, 2013).

A study carried out by the University of Cape Town demonstrated an optimistic output of 15 % renewable energy by the end of 2020 (Winkler et al., 2016). Despite this, the growth of renewable energies (wind and solar) has been slow (Pegels, 2010; S.A. Government, 2011; Meakin et al., 2013; Henneman et al., 2016). Shale gas development presents a vital option and optimum pathway in the energy transition development (Hultman et al., 2011; Cathles et al., 2012; O’Sullivan and Paltsev, 2012; Glazewski and Esterhuyse, 2016).

3.3 Sustainability and the Energy Trilemma

A ‘sustainability energy transition’ is a structural switch from high polluting fossil-based energy systems to low carbon sources (Heffron et al., 2018). Increasingly, policymakers and energy researchers face the challenge of restructuring high-emission energy systems as sustainable sources. A sustainable transition model involves the coevolution and cogeneration of various factors (cultural, technological, ecological, economic, and institutional) (Rotmans et al., 2001a). Decarbonisation of the energy sector in South Africa is vital given that the country is coal-dependent, producing 92 % of national electricity and accounts for 45 % of the national GHGs emissions; therefore, prioritizing the ‘just transition’ pathway from ‘carbon lock in’ is critical to the realisation of a sustainable future (Table 6 & Fig. 19) (Baker et al., 2015). The South Africa policy (Integrated Energy Plan (IEP)) on decarbonisation integrates a contribution of low carbon energy options such as solar, wind and natural gas and adaptation of economic, social, and political factors (Altieri et al., 2015).

Table 6: Sources of Energy and Power Generation in South Africa.

Energy Source	Electricity Generation %
Coal	91.8
Natural gas	0.2
Nuclear	5.5
Hydro	2.1
Wind onshore	0
Solar PV	0
Solar thermal	0
Biomass	0

Source: Altieri et al. (2015).
Notes: South Africa relies on coal power for electricity generation and largest emitter of GHGs.

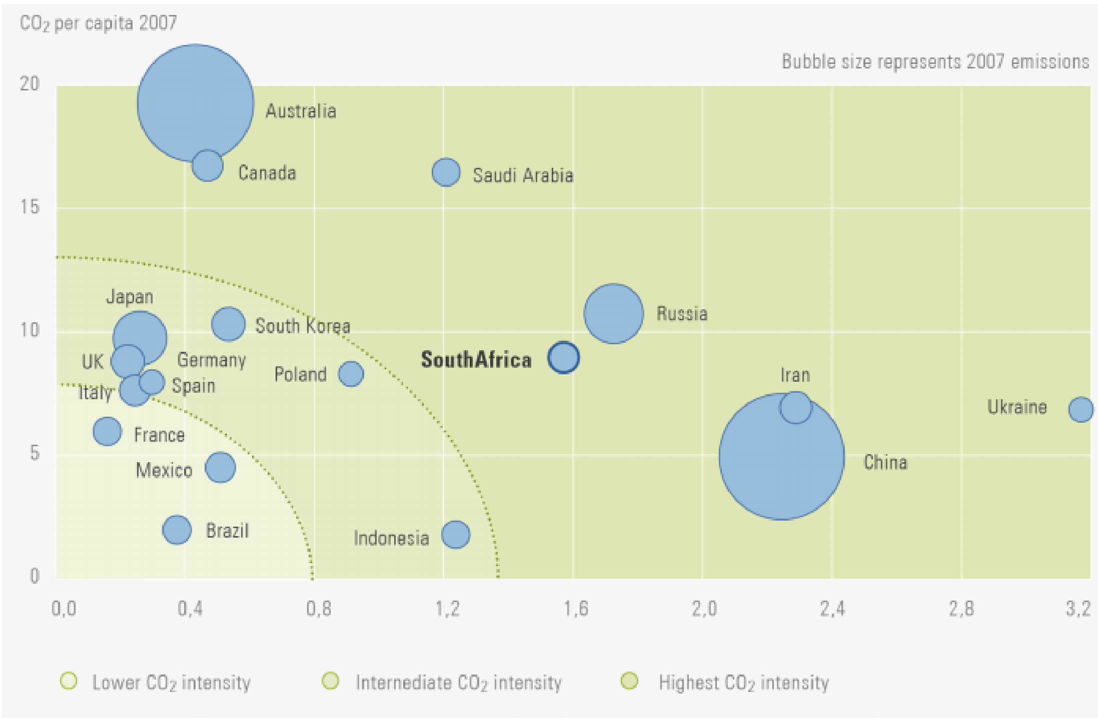

Figure 19: Global Greenhouse Gas Emissions Intensity.

Source: Altieri et al. (2015).
Notes: South Africa's energy sector is ranked as among the highest carbon intensity in the world reflecting the high share of coal in the primary energy mix.

Drawing from the transitions theory, energy researchers highlight the importance of solving the current energy and environmental challenges (e.g., anthropogenic emissions and climate change) associated with energy systems by setting long-term goals complementing current regulatory policies, coupled with strategic technological innovations (Walker, 2000; Unruh, 2002). Others have suggested adopting socio-technical transitions that are culturally and politically specific (Jänicke and Jacob, 2005). Smith and Stirling (2005) drew attention to the sustainability and structural nexus of energy systems as a legitimate agency of social choices.

Several studies have examined the potential of shale gas to facilitate the transition to a green future. Varaiya et al. (2011) noted that mitigating climate change entails lowering carbon dioxide emissions (CO_2) to net zero, advocating policy packages that enforce investment in unconventional energies and the necessary change in public behaviour regarding the development of new energy sources. Research demonstrates the importance of examining the complex socio-technical and environmental processes involved in advancing adaptable energy policy required to deliver sustainable energy development (Cotton et al., 2014). It should be noted that transitioning from fossil fuels to renewable energy is progressing slowly due to the competing forces of the 'energy trilemma'; energy security, climate/environmental sustainability, and economic competitiveness (Fig. 20) (Gallo, 2012; Umbach, 2012).

The discursive argument surrounding the energy trilemma has progressed to studies in low-cost energy solutions that prioritize the issue of energy burden (Newbery, 2016). There are many differences in opinion of what the energy trilemma entails. However, Coady et al. (2017) studied energy justice studies to compare the energy performance for different generating technologies. They developed a metric system to balance the energy trilemma required to deliver the best outcome for society (Fig. 21). The authors noted that balancing the competing frames of the energy trilemma is energy justice. This concept highlights the need to move away from elements of economic, political, and environmental benefits in policymaking to meet the allocation and equitable distribution of risks and benefits (Heffron et al., 2018).

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Figure 20: The 'Energy Trilemma'.

Modified from Heffron (2015).

Figure 20 shows that Energy Justice plays a critical role in the three points of the triangle. The trilemma is described below as emanating from Energy Justice in three areas:

- Economics – low cost, efficiency
- Politics – domestic politics, energy security
- Environment – environmental health, mitigate CO_2 emissions, reduce climate change

The trilemma creates a clear link that allows for a comprehensive analysis of emerging energy technology, perceived consequences decision making and policy implementation. Additionally, the trilemma permits an inclusive approach to sustainable energy development, prioritizing the country energy development framework regarding forward-looking scenarios, as shown in Fig.21.

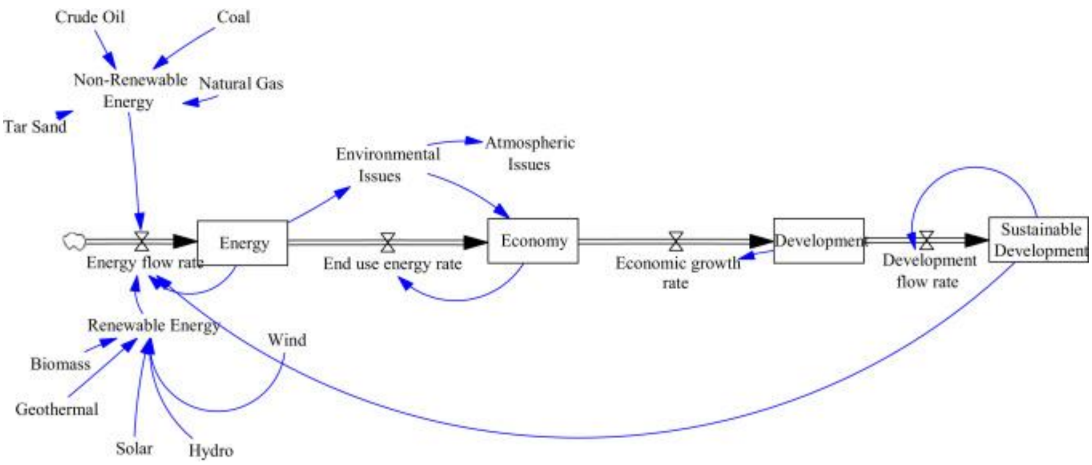

Figure 21: Schematic showing Analysis of Sustainable Energy Development.

Source: Elum and Momodu (2017).

Notes: The map provides an understanding of sustainable energy development and traces the intersection between renewable and non-renewable energy sources.

3.4 Analysis of Moral Thought of Energy Development

Researchers have demonstrated the importance of engaging with environmental science and risk perception studies beyond the technical and geological consideration of shale gas development to understand how shale technology is interpreted and framed by sociocultural values. Even so, discussions about energy and environmental policy decisions often disregard the limits of science and fail to capture public thought in energy policymaking and impact on indigenous lands (Jasanoff, 2010; Brace and Geoghegan, 2011).

The varying arguments about the potential environmental impact of shale gas development have stimulated interest in addressing the ethics of deploying the technology in indigenous communities. Much has also been documented in the literature concerning environmental justice and its implications for indigenous people's rights to energy and technological development (Willow, 2014). Zimmerman (2005) pointed to the weakening of indigenous people rights in policymaking, including issues related to environmental sustainability and energy development. In contrast, claims about the ethics of shale gas development and its application to local communities are common in literature. Evensen and Stedman (2017) found that most ethical concerns about shale gas development are grounded on issues related to ecological and environmental changes that conflict with the broader values of the local community, including the nature of distributive justice and rights-based procedural arguments.

Furthermore, studies hint at the implications of the ethical and environmental dilemma surrounding shale gas development in the local community (Cotton et al., 2014). Cotton et al. (2014) pointed to the role that argumentative (social or public) discourse plays regarding the fair distribution of benefits to the local community while mitigating the potential impact caused by shale gas development on the environment, allaying public concerns related to underground water contamination, impact on air quality and other exogenous impacts. The limited scholarship in this area points to the need to explore further the mechanism and processes in which ethics are framed in energy policymaking. Even so, the framing of ethical claims and their value for decision making translates beyond scientific thinking to include an interdisciplinary approach (Tebele, 2016; De Beer, 2018).

The debate over shale gas development is characterized by an apparent lack of expert consensus over the environmental impacts. Therefore, our understanding hinges on several factors, ranging from the complexity of the technology, the lack of empirical data on its application, and differing or contested society's values on how to balance the benefits over the environmental impacts (Konschnik and Boling, 2014). However, shale development is of interest as the government endeavours to position the country as an emerging player in shale gas development in Africa. It is not surprising that pro shale gas development frames South Africa Government energy policy and its response to environmental issues. Notably, energy security, economic opportunities, and the role shale gas could play as a ‘bridge fuel’ in mitigating emissions and achieving environmental sustainability are regarded as significant benefits of shale gas exploitation (Cotton et al., 2014; Bomberg, 2015).

3.5 Democratizing Environmental and Energy Technology

Recent work in this area has been advanced by studies related to the environmental risks posed by fossil fuel development (Andreasson, 2018; Pietersen et al., 2021). Several studies have sought to demonstrate that citizen-expert inquiry may hold the key to addressing specific concerns related to the impact of shale gas on the environment (Eden, 1998; Healy and Barry, 2017). This current study advances that discourses about shale gas development should be held within society - not solely as a scientific inquiry but negotiations that encompass the public, cultural practice, environmental politics, and authority claims. Beck (1992a) coined the term `reflexive scientization' to suggest scientific inquiry to greater public scrutiny and criticism. Using the public (or lay people) as ‘extended peer communities' improves the democratization of scientific knowledge and its ability to situate risks and environmental/ technological uncertainties (Funtowicz and Ravertz, 1993). Extending environmental research into non-scientific/ social groups and cultural knowledge may cause institutions to change focus or develop self-critique in deploying energy systems, especially when the new technology is perceived to introduce significant risks to the environment, compromise public wellbeing and safety. Researchers have argued that incorporating public knowledge at the local and institutional level will create a balanced perspective of the discourse and introduce diverse expertise into environmental policy and the deployment of energy technologies (Fischer, 2000; Bäckstrand, 2003). Ideally, contextual knowledge grounded from individual experiences and traditional/ cultural factors, especially moral knowledge that traditional scientists often ignore, would encourage social representation in the discourse and enable/ empower indigenous communities to function as ‘global citizens’ in providing solutions to environmental and energy-related issues. In this way, lay expert studies make a critical contribution to the growth of environmental policy and offer a more accurate picture of the impacts of energy policy decisions. Frumhoff et al. (2015) suggested that an enhanced focus on social interests and values will be required to hasten energy transition.

3.6 Politicisation of Environmental Policy

Greater focus and recognition of the divestment of fossil fuel, including issues related to climate policy and framing of the energy transition, are critiqued in outlining indigenous communities' vulnerabilities (Newell and Mulvaney, 2013). Healy and Barry (2017) argued that the transformation of energy regimes and planning in heterogeneous societies (such as the Karoo South Africa) must align and focus national energy policy on social, cultural, and economic considerations by addressing equity concerns local landscape. Studies have demonstrated that the level of energy poverty and inequalities in South Africa, including the complex power play and social actors, underly the fair distribution of resources (May and Govender, 1998; Büscher, 2009; Baker et al., 2015; Falchetta et al., 2020). Newell and Mulvaney (2013) and Unruh (2002) recognized the value of a 'just transition' that addresses the socio-political inequalities and the social costs of energy development impacted on society. Chomsky (2016) and Newell and Mulvaney (2013) posited that the dangers of the 'green new deal' or 'just transition' on vulnerable communities could produce unpredictable results and conditions that allow political institutions and state to perpetuate social injustice by active engagement in indigenous resources development. This has huge implications for shale gas development in the Karoo as the movement towards the energy transition intensifies and overlaps with the legacy of systematic/ historical socio-political inequalities (Baker et al., 2015). Given the politicization of environmental and energy policy and its role in shaping society's structure, any transition in a heterogeneous community is likely to bypass distributional justice or enhance the energy transition at a great price of environmental justice.

3.7 Environmental Concerns Specific to the Karoo

The development of shale gas is rapidly emerging as a relatively low-cost unconventional energy system with significant economic, social, and environmental benefits (Andreasson, 2018). Shale plays are widely distributed in sedimentary basins and exploited in many countries through the application of hydraulic fracturing and horizontal drilling techniques. 38% of global shale resources are in arid areas or places experiencing extreme water stress thus increasing the risk of water depletion. The Karoo is a semi-arid region with dryland vegetation experiencing very low rainfall between 150–350 mm yearly. Therefore, the excessive use of water threatens the biodiversity and fragile ecosystem of the Karoo (Le Maitre et al., 2007; Gallo et al., 2009; Toerien, 2020). The Karoo is an ecologically sensitive territory that is high on the radar of environmental conservationists. Le Maitre et al. (2007) presented empirical evidence to demonstrate the impact of human and energy activities on the fragile Karoo ecosystem. The threat posed by water requirement for shale gas development continued to come into sharp focus. Water footprint is perhaps the most critical environmental issue associated with shale gas development in South Africa. Areas of public concern include the management of water for domestic purposes and all users in the agriculture sector (Reig et al., 2014). The intense water requirement for shale gas development increases the challenge of moving forward with shale gas development in the Karoo, however, evidence suggests that risks on domestic water and cumulative impact on freshwater usage for shale gas development usage can be mitigated by strict regulatory enforcement/ standards, effective water management plan, recycling of produced water and innovative water technology solutions (Vandecasteele et al., 2015; Annevelink et al., 2016).

An average shale well requires between 3500 m^3 to 50,000 m^3 per shale well (Vandecasteele et al., 2015). Maloney and Yoxtheimer (2012) measured the recycling rate for flow back or produced water in the Marcellus shale and found that 70 % of the flow back water can be recycled and reused, reducing the amount of freshwater for shale gas activities. However water requirement for new fields Karoo Basin may be significant compared to water used in a matured shale field. The scale of fresh water use in the Karoo is fully apportioned to various grazing and irrigation purposes; therefore, water requirement for shale gas development would need to be sourced from non-potable/ freshwater sources such as deep saline groundwater or sourced externally outside the Karoo. Improved technological innovation in water treatment, such as reverse osmosis (RO) desalination of saltwater, has significantly impacted and reduced non-potable water sources for shale gas development. Given the advances in the water management plan Vandecasteele et al. (2015) demonstrated 28 % withdrawal of domestic water for shale gas development (Fig. 22).

A study conducted by the Endocrine Disruption Exchange (TEDX) identified over 944 chemical products used by different companies for hydraulic fracking activities (cited in Maule et al., 2013). The study noted that 75% of the chemicals directly or indirectly affect the human skin, gastrointestinal and respiratory system. In addition, 50% of the chemicals were known to affect the immune system, circulatory system, and nervous system (Colborn et al., 2011;

Struchtemeyer and Elshahed, 2012; Rogers et al., 2015; Hurley et al., 2016). Elsner and Hoelzer (2016) reported that an average of 25 different additives and chemicals used for the hydraulic fracking process has been reported to be hazardous and classified as dangerous compounds.

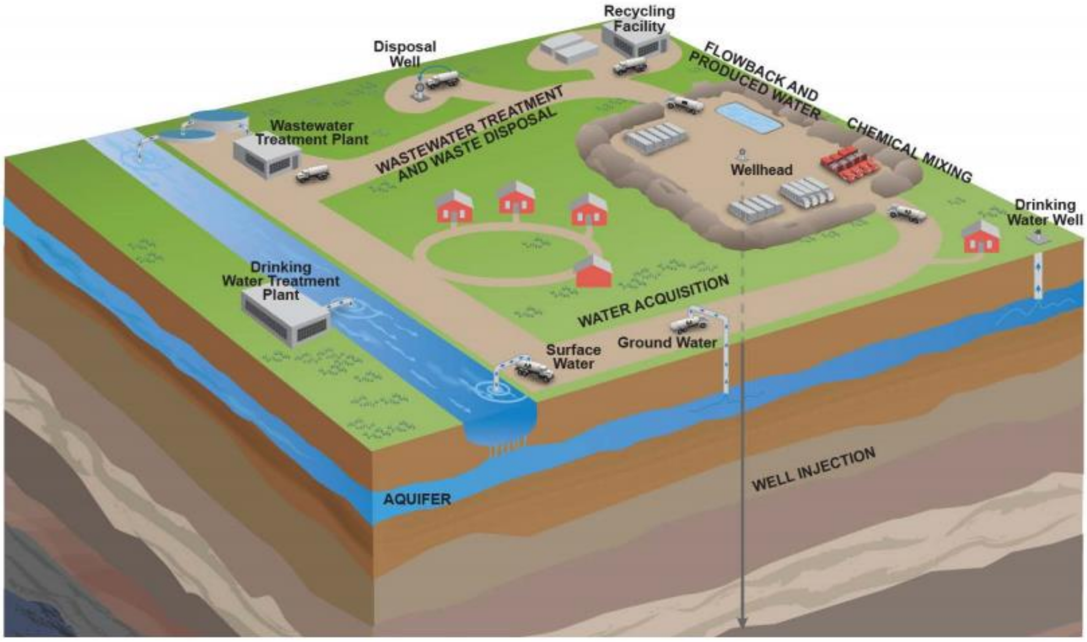

Figure 22: The Water-Energy Nexus of Shale Gas Development.
Source: U.S. EPA (2012). Not to scale.
Notes: Water is a vital aspect of shale gas development; from acquisition, chemical mixing, hydraulic fracturing/ injection, flowback and produced water, wastewater treatment and disposal. Water requirement can reach up to 6 million gallons (27,276,552 litres) per shale well. Studies have found that agricultural and other industrial activities consume more water than shale gas development. Source: U.S. EPA (2012) & Freyman (2014).

The release of fugitive emissions from shale gas activities and the overall increase in greenhouse warming potential constitutes a significant aspect of public concern in the Karoo (Willems et al., 2016). Empirical studies suggest that emissions of pollutants such as ozone precursors from shale gas activities are uncertain and impacted by different factors (based on operating conditions and regulations) (EPA 2011; O'Sullivan and Paltsev, 2012). Therefore, the rate of emissions will vary across the operation's life cycle. Impact on air quality is likely to be significant as more shale wells are drilled, and development becomes clustered in the basin (Fig.13). Although studies across the US shale play have demonstrated a substantial impact on air quality and ozone formation (Howarth et al., 2011a), similar baseline studies will need to be established in the Karoo to fully assess the impact on air quality to support planning decisions and mitigation strategies. It is recommended that empirical studies are conducted in the Karoo to extend the South Africa evidence base and evaluate the transferability of the US experience to South Africa. Reduced emission completions (RECs) such as the green completion technique are employed during flow back to reduce methane emissions and other VOCs to the atmosphere (Clark et al., 2012; EPA, 2011b; Harvey et al., 2012).

The findings of Howarth et al. (2011b) and Hultman et al. (2011) have been challenged by studies carried out by DOE (2011) and Cathles et al. (2012) and have come to different outcomes about the relative impact of GHG from shale gas activities. Burnham et al. (2011) argued that GHG emissions from shale gas operations are significantly less than conventional oil and gas.

3.8 Hydrogeologic Control and Dynamics of the Karoo

Planned shale gas development in the semi-arid Karoo Basin has resulted in a comprehensive assessment of the hydrodynamic character of aquifers in the region (Murray, 2015 and Swana, 2016). The active groundwater wells in the Karoo are producing freshwater from shallow aquifers located within 200 m from the ground surface (Eymold et al., 2018). Studies by Rosewarne et al. (2013) highlighted that the seasonal variation of the water table ranges between 5 and 15 m with preferred groundwater flow controlled topographically across the basin. Recharged of the aquifer systems occurs during the flooding seasons mainly in fractured areas of the Karoo basin including zones with dolerite intrusions and fractured contacts/ discontinuities in the Ecca Group, Beaufort Group (Adams et al., 2001; Johnson et al., 2006; Mahed, 2016).

The vulnerability of the aquifer to fluid contamination appears to be the most critical concern to shale gas development, given the scarcity of freshwater sources. In addition, the Karoo is challenged with little rainfall and extreme drought conditions (Walker et al., 2018). While potential risks to surface water bodies can be mitigated promptly, however the effect on subsurface water systems are usually broad and have longer consequences, are extremely difficult to mitigate and often extend on a regional scale. The hydrodynamic conditions of deeper wells (>1,000 m) in the Karoo are relatively unknown (Harkness et al., 2018).

3.8.1 Impact of Dolerite Sills and Intense Fracturing

Studies from the Karoo Basin demonstrate that discrete channels of hydrocarbon accumulate in stratigraphic and structural traps (Talma and Esterhuyse, 2015). These observations suggest that local and regional structural faults and fractures control the migration of hydrocarbons. Traces of high salt-rich fluids from deep source rocks have been found in the Karoo Basin in shallow aquifers (Harkness et al., 2018). These observations in the Karoo are consistent with findings from other shale basins (Darrah et al., 2015b; Moritz et al., 2015; Humez et al., 2016; Wen et al., 2016 and Harkness et al., 2018). Studies and reservoir evaluation from wells drilled in the Karoo Basin found traces of saltwater and hydrocarbon deposit in discrete discontinuities located in structural and stratigraphic traps (Rowsell and De Swardt 1976; Talma and Esterhuyse 2015; Eymold et al., 2018).

The study found that dolerite sills and intense fracturing zones provided preferential channels for the migration of methane and saline rich fluids from greater depth to shallow aquifers in the Karoo. Studies have found remnants of deep meteoric water and salt-rich fluids (thermogenic methane-rich groundwater) in shallow aquifer in the Karoo Basin may have transferred through structural discontinuities during hydrocarbon migration (Ballentine et al., 2002; Darrah et al., 2015b; Harkness et al., 2018). Similar observations have been identified in shallow aquifers in shale basins around the world (Darrah et al., 2014; Moritz et al., 2015; Darrah et al., 2015a, 2015b; Humez et al., 2016; Wen et al., 2016; Harkness et al., 2017a; 2017b; 2018). However, the incursion may have taken a prolonged period due to the large scale given the role played by the geological time scale as a control mechanism (Moortgat et al., 2018).

3.9 Design of Fracturing Fluids

Hydraulic fracturing fluid constitutes an important aspect of shale gas development. Hydraulic fracturing fluid defines all aspects of the physical and rheological properties required to optimize the wellbore and production of hydrocarbon. The fracking process involves the injection of "fracking fluid" (mainly water and a mixture of sand and proppants suspended with the support of gelling agents) into a wellbore to induce fractures or channels in the deep shale rock formations through which brine and natural gas will flow more easily (Figs. 23 & 24). The fracturing fluid serves a specific purpose (Tables 7 & 8) but vary in composition depending on the geology of the formation and objective of the well (Rahim et al., 2013). The base fluids additives and proppants are used primarily as friction-reducing agents to prevent the growth of bacteria and degradation of the fluid.

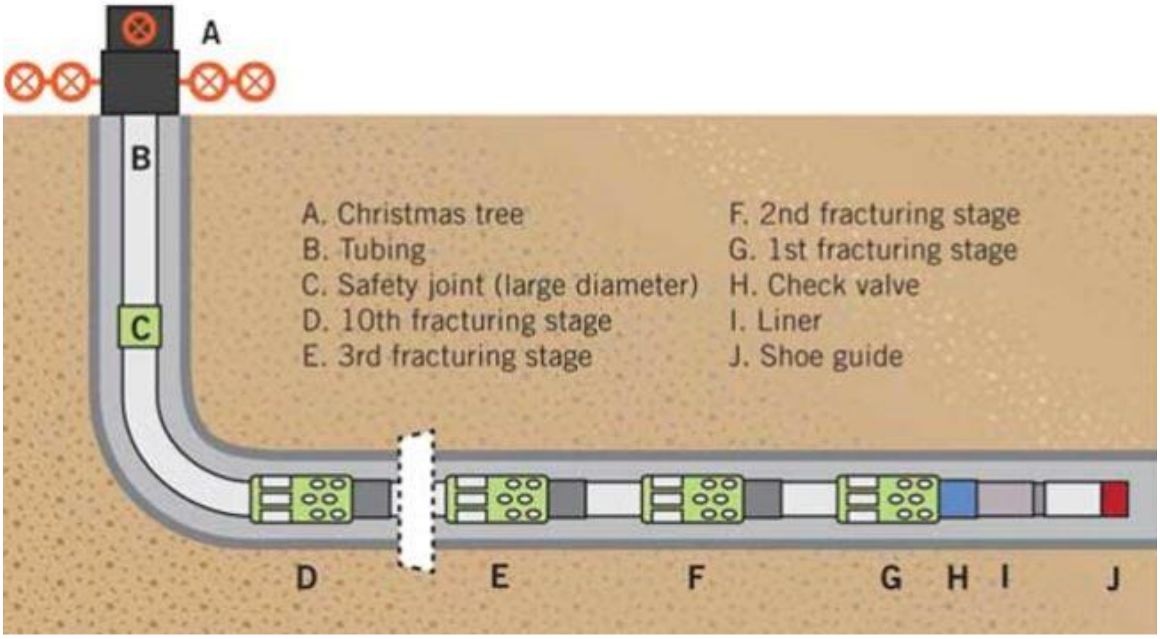

Figure 23: Multi-stage Fracking of Horizontal Wells.

Source: Jinzhou et al. (2013).

Notes: The application of horizontal drilling with multistage hydraulic fracturing is used in developing unconventional reservoir. The process involves stage fracking, isolation, and gas flow into the wellbore.

Table 7: Function of the Chemicals in Fracturing Fluid.

Additive	% by weight	Purpose	Examples
Proppant	9	Proppant opens fractures	Ceramics/ Quartz sand (0.4–0.8 mm in diameter)
Acid	0.400	Cleans up perforations, dissolve some rocks	Hydrochloric acid
Breaker	<0.001	Reduces viscosity, promotes flow back	Peroxydisulfates
Bactericide/biocide	0.020	Control bacterial growth	Glutaraldehyde, formaldehyde, methylisothiazolinone
Buffer agent	-	Adjusts/controls acidity	Sodium (or potassium) carbonate, acetic acid
Clay stabiliser	-	Prevents clay swelling/migration	Potassium chloride
Corrosion inhibitor	0.001	Prevents rusting of pipes	Ammonium bisulphate, methanol
Crosslinker	-	These have higher viscosities and break down less	Potassium hydroxide, borate esters, vinylidene
Friction reducer	0.090	Reduces friction between the fluid and the wellbore	Sodium acrylate, acrylamide copolymer, petroleum distillates (benzene, ethylbenzene, toluene, xylene, naphthalene)

Gelling agent	0.001	Increases fluid viscosity to carry more proppant into fractures	Guar gum, cellulose polymers, petroleum distillates (benzene, ethylbenzene, toluene, xylene, naphthalene)
Iron control	0.02	Prevents precipitation of iron oxides	Ammonium chloride, ethylene glycol
Solvent	-	-	Various polyaromatic hydrocarbons (PAHs), benzene, toluene
Surfactant	0.100	Reduce the fluid surface tension to aid fluid recovery	Methanol, isopropanol, ethoxylated alcohol, ethylene dichloride

Source: Nonita (2016).

Notes: The physical properties of hydraulic fluids range from dilute acids, breakers, biocides, gels, crosslinkers, friction reducers, oxygen scavengers, corrosion inhibitors, pH adjusting agents, scale inhibitors, potassium chloride and surfactants making up 2 % of the fluid. The remaining 98 % of the fluid is water.

The different types of hydraulic fracturing fluids and range of additives are presented below:

Water-Based Fluid: is the commonly used fracking fluid for most shale gas activities and made up of 80-95% water, clay, and a range of friction reducer. In some condition, a water recovery agent (WRA) is added to optimise the relative permeability of the fluid and clear the block effects of the water. Water Frac is economical than the other fluid types. It is easy to mix, treat and recycled for subsequent use.

Linear Gel: made up of water, clay, and Guar Gum. Bactericide and chemical breakers are also added to reduce the growth of bacteria and potential damage of the proppant. Linear Gel has improved viscosity properties that effectively control fluid loss, however, produced water from the well is not reusable due to the concentration of residual breaker in the water.

Crosslinked Gel: made up of water, clay, Guar Gum and crosslinker added to increase the viscosity of the fluid in order to enhance the transport of proppant, build the filter cake and prevent fluid loss to the formation.

Oil-Based Fluid: commonly used in non-competent geological formation and water sensitive. The oil-based is made up of gasoline, palm oil and naphthenic acid/ cross-linker and effectively building a good filter cake to control fluid loss. The oil-based fluid is expensive to produce and have environmental safety and disposal concerns.

Foam/Poly-Emulsions: are colloidal systems in which oil exist in the dispersed phase of the emulsion and contain polymers, saturates, resins and aromatics. The fluid is adequate at all range of temperature and stabilises wellbore conditions.

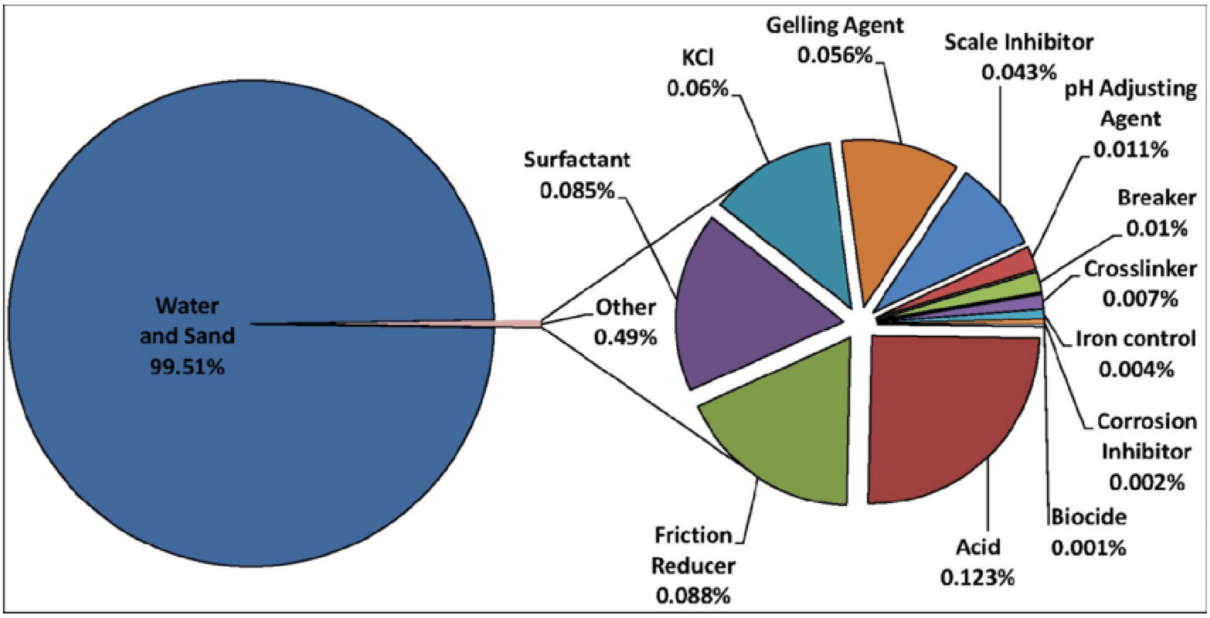

Figure 24: Composition of Fracking Fluid.
Source: Goldstein et al. (2014).
Notes: Hydraulic fracking fluid is composed of 98- 99% of water and sand, 1-2% of different chemicals/ additives.

Table 8: Additives and Domestic Use and Purposes.

Additive	Domestic Use/ Purpose
Breaker	Hair Cosmetics, Household Plastics
Acid	Household Cleaner, Swimming Pool Cleaner
Bactericide/biocide	Disinfectant, Used to Sterilize Medical Equipment
Gelling Agent	Toothpaste, Baking Goods, Ice Cream, Sauces, Cosmetics
Potassium Chloride	Low Sodium Table Salt Substitute
Corrosion inhibitor	Household Cleaners. De-icing Agent Pharmaceuticals, Plastics
Crosslinker	Soaps, Laundry Detergent
Friction reducer	Water Treatment, Candy, Make-up Remover
Gelling agent	Toothpaste, Baking Goods, Ice Cream, Sauces, Cosmetics
Iron control	Food Additive, Lemon Juice, Flavouring in Food & Beverage
pH Adjusting Agent:	Detergents, Washing Soda, Water Softener, Soap
Surfactant	Glass Cleaner, Antiperspirant, Hair Colour

Source: Montgomery (2013).
Notes: A range of hydraulic fracking chemicals are also used in industrial and household purposes.

The range of additives is shown in Figures 24 and 25.

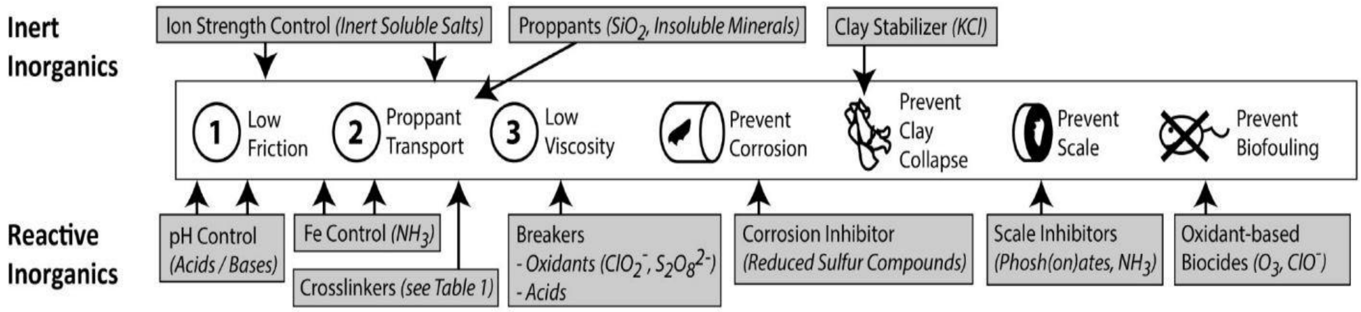

Figure 25: Chemical Composition of Hydraulic Fluid.
Source: Elsner and Hoelzer (2016).
Notes: The physical properties of hydraulic fluids are viscosity, density, scale, and corrosion inhibition.

Studies report between 10 and 30 stages of fracturing per well; however, the volume of water chemicals used to include the number of stages designed for hydraulic fracking purposes depends on a range of factors ranging from local geology, duration of drilling and well objectives (Vandecasteele et al., 2015; Pearson et al., 2013; Keshavarz et al., 2015). Multi-stage fracking of horizontal wells is broadly used in tight and shale reservoirs. The fractures are propagated at clusters of 6–32 and spaced between 10–30 m. As such, multiple fracking operations are used primarily to enhance well performance. At the same time, the fractures provide the pathway for fluid flow and gas production from the reservoir to the wellbore (Fig. 26) (Yao et al., 2013).

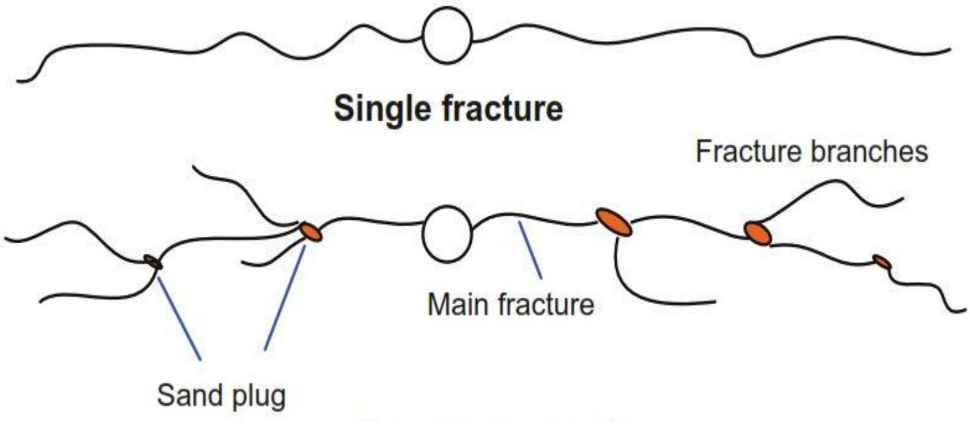

Figure 26: Fracture Propagation induced by Hydraulic Fracturing.
Source: Zeng et al. (2015).
Notes: Branches of multiple fractures are initiated perpendicular along the wellbore, in the direction of minimum stress.

3.9.1 Potential Pathways of Fluid Leakage

A blend of formation water and fracturing fluid is referred as flowback. The flowback is contained at surface tanks several days after the well is fractured and produced (Nicot and

Scanlon, 2012; Butkovskyi et al., 2017). Flowback water contains a blend of salt, oils, volatile and heavy metals pumped into the well for fracking purpose (Gregory et al., 2015; Shih et al., 2015), while produced water is the natural formation fluid in the shale reservoir, which may be reused and reinjected into the well after treatment (Shih et al., 2015; Annevelink et al., 2016; Butkovskyi et al., 2017). Untreated wastewaters are disposed of in underground wells (Rahm et al., 2013; Nicot et al., 2014). However, wastewater treatment is gaining significant attention, especially in Europe, where legislation prohibits the disposal of hazardous substance in underground wells (Butkovskyi et al., 2017).

Rozell and Reaven (2012) identified five potential pathways of fluid contamination during the life cycle of shale gas development: (a) spills resulting from produced water; (b) leaks from casing; (c) leaks during hydraulic fracturing; (d) discharge from drilling activities; (e) disposal of wastewater. Studies have found that wastewater carries the largest risk for surface and underground water contamination. Vidic et al. (2013) observed that well integrity/ cement failure generates crossflow between formation fluid and groundwater sources. Legere (2013) reported that most documented pollution has resulted from well integrity failures which can be mitigated through best practice. Fluid migration is linked with the deterioration of the structural integrity of the well and cement failure. Well integrity failures may allow the intrusion of gases and fluids from the reservoir from shallow gas- and fluid-bearing formations intersected by the wellbore to lower-pressure formation. Geologically, shale reservoirs have extremely low permeabilities (ranges from 3.9×10^{-6} to 9.63×10^{-4} mD); therefore, fluid migration and contamination into overlying strata is likely to be minimal under normal conditions requiring extensive geological timescales for significant invasion into shallow bodies (Yang and Aplin, 2007; Davies et al., 2014) (Fig. 27). Figure 27 shows the risk matrix and the potential pathways of contamination.

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Figure 27: Risk Matrix and Potential Pathways of Contamination.
Modified from Rozell & Reaven (2011) & Krupnick (2013).
Notes: The matrix of severity, likelihood and significance of pathway covering all aspect of contamination and environmental impact.

Studies suggest that wastewater disposal, including recycling/ treatment, carry the most significant risk or pathway for water contamination (Fig. 27) (Rozell & Reaven 2011; Estrada and Bhamidimarri, 2016). Vidic et al. (2013) highlighted that casing, and cement failure presents a viable pathway for transition fluids to migrate and contaminate groundwater sources. Legere (2013) argued that well integrity failures from oil and gas well operations between 2008 and 2012 resulted in the pollution of domestic water sources in Pennsylvania. The wastewaters can release toxic chemicals into the water cycle through migration pathways (Rozell and Reaven, 2012).

3.9.2 Empirical Analysis

The use of hydraulic fracking to simulate the well is initiated at significant depth between 2000 m to 3000 m (Jackson et al., 2015). Fractures created at this depth are restricted to freshwater bodies. In addition, the presence of impermeable shale layers acts as a potential barrier for the vertical propagation of fractures limiting the influx of contaminants to shallow water bodies (Lei et al., 2008; Uguru et al., 2011). Formation penetrated by wellbore that has not been properly isolated can result in shallow water contamination (Fig. 28 & Table 9). Wang et al. (2014) demonstrated that casing damage from poor cement jobs provides the channel cross flows. Studies by Osborn et al. (2011) and Jackson et al. (2013) showed methane contamination of water wells less than 1 km from the fracking site. The average methane contamination was 19.2 mg/L, seventeen times higher than wells beyond 1 km in the Marcellus. Osborn et al. (2011) found that the source of the methane was of thermogenic origin, consistent with the generation of hydrocarbons in deeper wells. Jackson et al. (2013) found water wells less than 1 km to the fracking location have six times the methane concentration, twenty-three times ethane values, ten times propane.

Study by Warner et al. (2013) did not find any spatial correlation between the concentration of methane in water wells and distance to the fracking location. Davies (2011) and Saba and Orzechowski (2011) argued that Osborn et al. (2011) used a small drinking water sample for their analysis with no baseline data to compare the effect of distance on methane concentration. Although the authors found some presence of thermogenic gas in water wells in the Marcellus area, however, no empirical evidence has been found to suggest that shale gas development was the reason for elevated levels of methane concentration in the water wells (Davies, 2011; Saba and Orzechowski, 2011; Zhang and Tingyun, 2015). Zhang and Tingyun (2015) highlighted the importance of confirming the origin and source of methane in water wells in order to establish if shale gas development was responsible for the elevated levels of methane concentration. Fontenot et al. (2014) carried out a similar analysis in the Barnett Shale. The study found high levels of dissolved solids, Arsenic (Ae), in water samples 3 km from the shale gas development site.

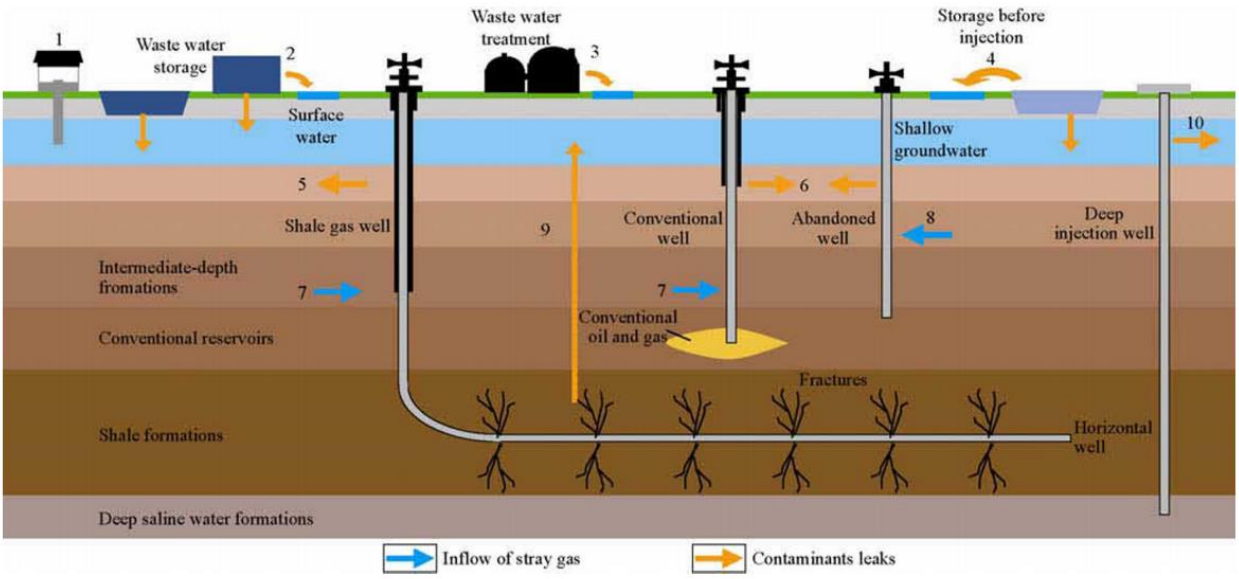


Figure 28: Environmental Risks associated with Shale Gas Development.

Source: Zhang and Tingyun (2015).

Not to scale.

Notes: Shale gas development has the potential of contaminating soil and sediments. Seepage of drilling/ fracking fluids may increase soil acidity and salinity. Pollutants may also contaminate the surrounding environment during erosion or runoff.

Table 9: Risks Associated with Shale Gas Development.

SN	Associated Risks
1	excessive use of water leading to depletion and water quality degradation
2	surface and shallow groundwater contamination due to spills and leaks from water storage and pits
3	disposal of wastewater of inadequate treatment leading to contamination of streams and soil
4	leaks from storage ponds used for deep-well injection
5	shallow aquifer contamination by gas, fracturing fluid and produced water leaked from casing;
6	shallow aquifer contamination by stray gas leaking from the casing or abandoned wells
7	stray gas originated from intermediate geological formations flowing into shale gas wells and/or conventional oil and gas wells, which may then leak from damaged casing
8	stray gas originated from intermediate geological formations flowing into abandoned well, which may then leak and contaminate a shallow aquifer
9	gas and saline formation water migrating directly from shale formation to shallow aquifers
10	shallow aquifer contamination by leaks from injection wells

Source: Zhang and Tingyun (2015).

Notes: Table shows the risk domains that have received the greatest attention. The adverse risks could be addressed and mitigated through best practices and regulatory/ effective oversight.

3.10 Water Footprint and Evolving Discourses on Water Requirement

The development of shale gas has important implications regarding domestic water utilization for the Karoo (Richardson et al., 2013; Pietersen et al., 2021). The water footprint is a globally accepted indicator that measures the rate of water consumption and the overall water withdrawal over the production cycle of industrial activities and energy development (Mekonnen et al., 2015). Recent studies examining the depletion of portable water sources are helping to understand the water footprint of shale gas development and to examine the impact on local and regional water systems (Mulovhedzi and Esterhuyse, 2021; Saha et al., 2021; Suboyin et al., 2021). The water is utilized primarily for chemical mixing, treatment of the fracking fluid and injected for fracturing of the formation (Fig. 24). Even so, studies have suggested that shale gas development required less volume of water (Zhang and Tingyun,2015) (Fig. 29, Table 10). Kondash et al. (2018) noted that the life cycle of a shale gas well may require 84 million gallons of water which is significant for areas (such as the Karoo) experiencing drought or water scarcity. However, the volume of water consumption listed in literature required for shale gas development depends on a range of factors such as reservoir characterisation, fracture design and number of fractures initiated during the fracturing activities. The volume of water used to frack and complete a shale well is geologically and geographically dependent.

The water footprint for shale gas development is classified in two major ways:

1. Water consumption for shale gas development activities
2. Water contamination resulting from shale gas development activities

Table 10 shows the range of water requirement of the major shale play in the US. As discussed, the volume of water used for hydraulic fracturing operations depends on a number of factors such as the local geology, duration of drilling and the objective of the well (Groat and Grimshaw, 2012).

Studies have indicated that an average shale well requires 5 to 9 million gallons of water per well with 10 % of the water injected during hydraulic fracking process returns as flowback to the surface. That implies that approximately 90% of the injected fluid is sequestrated into the formation thus damaging the petrophysical and hydrodynamic properties of the reservoir (Suboyin et al., 2021). The loss of water during shale gas development is fundamentally different from depletion experienced from agriculture, recreational activities (golf courses) and hydro electricity generation which loss water to the atmosphere through evaporation. The loss of water from these activities through evaporation returns back to the source as precipitation while losses during hydraulic fracking goes into deep geological strata, outside the natural hydrogeologic cycle.

Abdalla and Drohan (2010) estimated 28 million gallons of water required to complete an average shale gas well. Clark et al. (2013) carried out studies to investigate the direct and cumulative use of water for hydraulic fracturing activities across the four major shale plays in the US and found that the volume of water required to drill and complete an average shale well range from 10,600 m^3 to 21,500 m^3. Le (2018) argued that an average of 12–20 million litres of water per horizontal well are required to develop a shale gas well. Wang et al. (2018) reported that a significant volume of water is required to develop an average shale gas well in China (between 9,700–37,500 m^3 per well).

Nicot and Scanlon (2012) & Costa et al. (2017) highlighted that large water withdrawals for shale gas activities may lead to a significant decline in hydrodynamic pressure of the surrounding lakes, rivers, and streams. Gallegos et al. (2015) found that shale gas development results in unfavourable competition with other industrial activities. Nicot and Scanlon (2012) reported that water use for shale gas operations is comparable to water consumption by other industrial activities (such as coal and uranium mining) (Figs. 29 & 30).

The EPA estimated that an average of 25,000 to 30,000 wells are fractured in the US each year (Groat and Grimshaw, 2012; EPA, 2016). The acceleration of shale gas development puts a significant stress on local water supply. The EPA attributed an average of 0.2 % of total water withdrawal in Texas each year to shale gas activities (EPA, 2016). Scanlon et al. (2014) reported a decline of up to 200 feet (60 m) in hydrodynamic pressure due to significant water withdrawal for hydraulic fracturing activities in the Permian and Eagle Ford Basins.

The development of energy resources and water are intricately dependent and connected. All sources of energy and production technologies require significant volume of water in their life cycle processes (Figs. 29 & 30; Table 10). The amount of water required for exploration and distribution of energy for use is referred to as energy intensity. The energy water dependencies (nexus) is an important criteria to be considered in the strategic plan of energy development considering the high risk that shale gas development is exposed to.

Mekonnen et al. (2015) demonstrated a positive correlation between energy production and water consumption (Fig. 30). Hydraulic fracking activities is the only water intensive operations in shale gas development.

Shale gas development is water efficient compared to other energy sources (such as corn-based ethanol) (Fig. 29) (Ernstoff and Ellis, 2013). Researchers agreed that the volume of water used for shale gas development is small compared to other energy application, agricultural and industrial activities (Groat and Grimshaw, 2012; Mekonnen et al., 2015; Zhang and Tingyun, 2015). Water intensity for shale gas operations ranges from 0.84 to 1.32, million Btu per gallon (Figs. 29 & 30) (Groat and Grimshaw, 2012).

Given the environmental and social impacts of water consumed in shale gas development, energy companies are developing conservative approaches to sustain shale gas operations. These practices and conservative approaches are grouped into three classes such as using non portable water sources (low quality water), using reusing and recycling of flowback waters and developing infrastructure to facilitate water transport (Saha et al., 2021).

Table 10: Comparative Water Requirement.

Table removed for copyright reasons

Modified from Laurenzi and Jersey (2013); Clarke et al (2014); Groat and Grimshaw (2012).

Notes: The hydraulic fracking water footprint outperforms other fuel types in terms of water intensity per net energy usage. Researchers have indicated that other human activities like golf and farmlands consume more water than fracking.

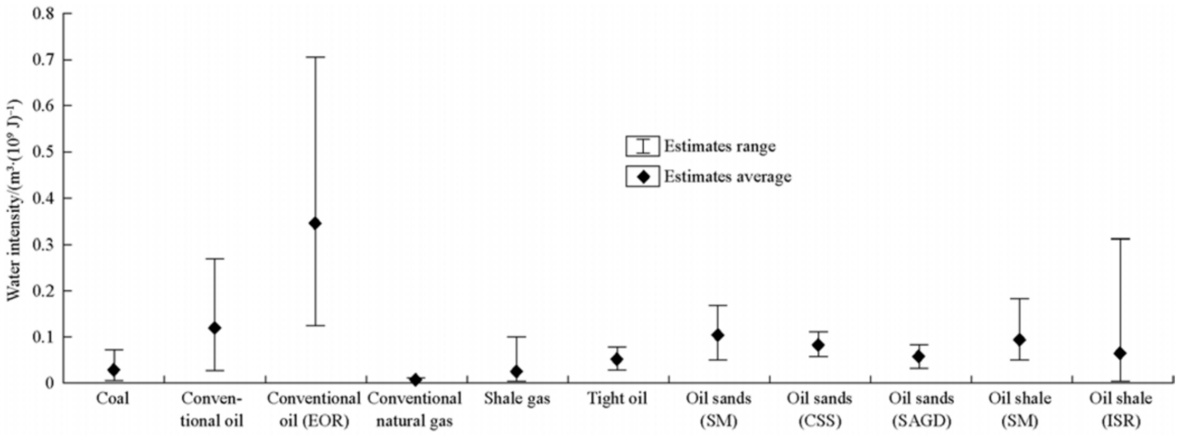
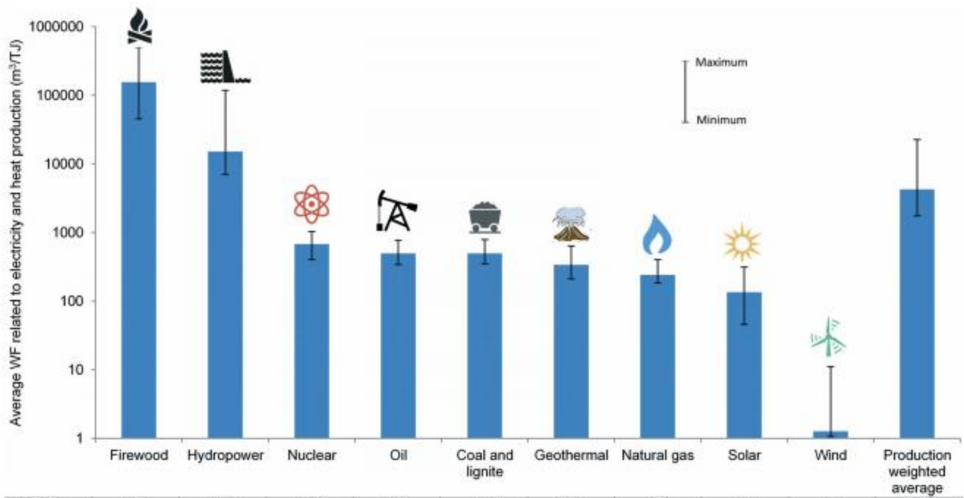


Figure 29: The Water Footprint (WF) of Different Sources of Energy
Source: Zhang and Tingyun (2015).
Notes: Figure shows less pressure on water requirement for shale gas development compared to other uses.



	Firewood	Hydropower	Nuclear	Oil	Coal and lignite	Geothermal	Natural gas	Solar	Wind	Production weighted average
Operation	400	15100	610	440	440	340	240	50	0.2	2410
Construction	0.4	0.3	0.3	1.1	1.1	2.1	1.1	90	1.1	1.0
Fuel supply	156000	0	68	55	54	0	6	0	0	1830

Figure 30: Average Consumptive WF per unit of Electricity and Heat Produced
Source: Mekonnen et al. (2015).
Notes: The ranges shown reflect minimum and maximum values per energy source. The values in the table represent the WF (m^3 TJ^{-1}) for the three main stages of the electricity and heat production chain (for the period 2008–2012).

3.11 Evolving Discourses on Air Quality

The prospect for compromised air quality in areas of large-scale energy development can be significant. At the same time, release of fugitive and toxic gases can originate from other energy development which has significant local and regional potential consequence on climate change and air quality. The effect on air quality from shale gas development is generally classified under two activities:

1. Fugitive emissions from drilling and production activities.
2. Emissions from vehicles/ wellsite equipment's or machineries

Empirical evidence suggest that shale gas development emits harmful air pollutants including BTEX (benzene, toluene, ethylbenzene, and xylene) and related toxic compounds such as hydrogen sulphide, sulfuric oxide, methylene chloride, trimethylbenzenes, aliphatic hydrocarbons, formaldehyde, acrylonitrile, nitrogen oxides (NOx), aliphatic hydrocarbons, volatile organic compounds (VOCs), radon gas and diesel particulate matter (McKenzie et al., 2012; Pétron et al., 2012; Roy et al., 2013). Findings by Howarth and Ingraffea (2015) verified that shale wells will leak or vents methane at some point in the life cycle of the well due to well degradation and poor management of the well.

Studies by McKenzie et al. (2012) found a high concentration of emissions exceeding health guidelines for non-carcinogenic and carcinogenic risks. The study also found that residents living close (> 0.5 miles) to shale gas facilities experience sub-chronic non-cancer related impact from direct exposure to hydrocarbons. Residence living at ≤ 0.5 miles to wellhead experience cancer-related impact. Shonkoff et al. (2014) challenged the validity of these results based on the use of inaccurate baseline air quality data. A study conducted by Bunch et al. (2013) found that emissions and exposure to VOCs from shale gas operations did not result in a community-wide impact or pose serious health concerns. The study monitored and compared the concentration of VOCs at multiple wellsite locations in Texas (Barnett Shale) and found no compelling evidence to confirm significant release of toxic air contaminant (TAC).

Roy et al. (2013) measured the concentration of PM, VOCs, and NOx in the Marcellus region. The study found that shale gas operation contributes an equal concentration (average of 12%) of NOx and anthropogenic VOC emissions to the atmosphere. Roy et al.'s (2013) results were estimated based on improvement in well completion and production activities. Elevated levels of VOCs and NOx in the atmosphere have been observed to complicate ozone production. Colborn et al. (2014) analysed the quality of air from samples collected weekly at the wellhead. These contained methane, ethane, propane, higher alkanes, and non-hydrocarbon compounds which are harmful to human health and contribute to air pollution.

Jerrett et al. (2009) confirmed the presence of tropospheric ozone (a secondary pollutant) generated through the reaction of VOCs, NOx with sunlight. Tropospheric ozone is a potentially dangerous respiratory and cardiovascular irritant. By contrast, air quality studies show that pure methane is not considered to be potentially dangerous to human health at the levels encountered (Smith et al., 2009). An aerial study carried out by Karion et al. (2013) found significant concentrations (12 %) of methane leaked into the atmosphere during gas production. Similar studies by Miller et al. (2013) observed elevated levels (4.9 times) of methane during gas production than the normal concentration. However, the result did not indicate the sources of leaks, either from gas production, transport, or storage facility. Peischl et al. (2013) modelled methane venting and leaks from oil and gas activities and found a 17% increase in methane levels in the atmosphere. Olaguer (2012) measured flaring from compressors at the wellsite and found that emission is released at > 3ppb up to 2 km from the wellhead. Schnell et al. (2009) observed a significant rise (140 ppb) in photochemical ozone during the winter months exceeding the normal concentration of 30 ppb. Proppant such as crystalline silica sand used to crack open fractures releases silica into the atmosphere during transportation to the wellsite and mixing operations. Esswein et al. (2013) investigated the effect of silica dust on direct exposure to workers and found that workers and people living close to drilling sites experience respiratory and kidney diseases such as silicosis. Silica dust was found to be 51.4 % greater than the normal exposure. Discrepancies in interpretation results in the way atmospheric data are captured and analysed explained why air quality estimates differ across context and studies (Shonkoff et al., 2014).

The US Department of Energy attributed significant increase of GHG to a dramatic rise in hydraulic fracturing activities (U.S. Department of Energy, 2011). Howarth et al. (2011a; b) argued that the upward trend of GHG was the direct result of gas vented to the atmosphere from flowback activities. Their study concluded that shale gas development has a higher GHG intensity than conventional oil and gas activities. In addition, several studies have suggested that shale gas development contributes more to global warming than coal energy (Howarth et al. 2011a; 1b). Researchers at the NOAA (National Oceanic and Atmospheric Administration) published a paper stating that fugitive emissions in the Colorado Denver Basin amounted to 3.8 % of the US total emission in 2008 (cited in Petron et al., 2012). The study assessed fugitive emissions from the entire gas field including pipelines, condensate plants, compressor stations, mid and upstream activities (Table 11). However, the findings have been challenged by several scientists as inconclusive given that the life cycle of GHG is slightly lower than conventional gas (Burnham et al., 2011; Cathles et al., 2012). Several researchers posit that coal power emits higher GHG than shale gas (Jiang et al., 2011; Stephenson et al., 2011; Weber and Clavin, 2012).

Table 11. Fugitive Emissions from US Shale Gas Wells in 2010.

	Barnett	Fayetteville	Haynesville	Marcellus	Woodford
Mean per-well potential fugitive emissions: (1 × 103 m^3 of natural gas)	273	296	1177	405	487
No. of horizontal wells	1785	870	509	576	208
Total potential fugitive emissions: (1 × 106 m^3 of natural gas)	487	257	599	234	101
Total potential fugitive methane emissions: (Gg CH_4)	262	138	322	125	54

Source: O'Sullivan and Paltsev (2012).

Notes: The argument in favour of shale gas development is significant in South Africa given the dividends of the shale boom in the US and contributed drastically to local emission reductions. However, if the rush for shale gas development comes with significant fugitive GHGs emissions, the argument to develop shale gas in the Karoo need to be assessed.

3.12 Evolving Discourses on Public Health

As with all fossil fuel extraction activities, emission of fugitive gases (methane and CO_2) from the life cycle processes and mechanical devices occur in the development and distribution of natural gases (Swarthout et al., 2015). Combustion from production tanks, compressors, pipelines, vehicles, generators, and the drilling rig constitute a potential source of emissions. Studies have found that ambient benzene and VOC increased by 40 % in areas actively engaged in natural gas development (O'Sullivan and Paltsev, 2012). However, studies by the Carnegie Mellon University, Institute for Energy Innovation noted critical gaps in knowledge at the intersection between the development of shale gas and public health and concluded that health risk may vary across different shale basins (The Carnegie Mellon University, 2013).

Toxic chemicals released into the atmosphere result from bad practices have been reported to cause pulmonary and respiratory related diseases and impact on life mortality especially for communities in close proximity to drilling operations (Apergis et al., 2021). Aryee et al. (2020) observed an elevated level of stress and anxiety in people living in areas where shale gas development is conducted. Perrow (2011) reported the increased frequency of accidental spills and ecological disasters in shale gas development areas. Explosion and wildfires have also been noted in these areas impacting community wellbeing. Bunch et al. (2014) found no evidence to suggest that VOC concentrated at the Barnett Shale region exceeded the HBACVs (Health-Based Air Comparison Values) chronic limits or constitute community wide exposure and threat to public health. Studies have demonstrated that flaring, engine combustion and condensate tank venting constitute the major channels for VOCs emissions rather than shale gas development (Bunch et al., 2014; Rich et al., 2014). These findings have significant implications on the debate and regulation of shale gas development. Therefore, the focus of research regarding the impact on public health should be broad (focusing on water, air, orphaned wells, greenhouse gases) and comparing/ noting how industry best practices and innovation can minimize the potential impact to the environment and public health.

3.13 Effects of Biogenic and Thermogenic Methane

Biogenic methane is produced at shallower depth and lower temperatures below 60 °C in the early digenetic process of hydrocarbon generation, primarily as a by-product of decay organic matter in terrestrial and marine environments and commercial settings such as wetlands, landfills, sewage, and agriculture locations (Heienz, 2010; Stolper et al., 2014; Teske et al., 2021). In contrast, thermogenic methane is produced by biodegradation (without the activities of microorganisms) of organic matter at a deeper depth and higher temperatures between 157-221°C (within the oil/ gas window). In addition, biogenic and thermogenic gases differ in their carbon isotopes, thermogenic gas contain significant amount of C^{13} while biogenic gas is mainly composed of $C^{12.}$ (King, 2012; Teske et al., 2021). The presence of methane has been reported in shallow water wells where shale gas development frames public concerns about gas leaks from hydraulic fracking operations (Howarth, 2011). Studies have confirmed the presence of natural surface hydrocarbon seeps 'outgassing' that may have escaped along structural discontinuities such as rock fissures and fractures or exposed geological outcrops. These events are not caused by hydraulic fracturing but natural occurring geological processes (Mangenot et al., 2021; Blouet et al., 2021).

High levels of dissolved methane have been found in water wells in areas active in shale gas development (Molofsky et al., 2013; Siegel et al., 2015). This is possible when water wells penetrate coal seams deposited at shallow depth, examples in Pennsylvania, Colorado, and California. Coals contain a significant measure of organic content and gas trapped in the organic matter is released on borehole penetration. In a properly constructed gas well, the shallow gas zone is properly isolated by suitable cementing and casing strings to prevent gas leaks to freshwater bodies. Likewise, exposure to deeper formations is isolated by the casing. Reports of methane emissions from orphaned wells from poor completion and abandonment practices have been documented as active source of methane emissions (Townsend-Small and Hoschouer, 2021; Saint-Vincent et al., 2021).

3.14 Induced Seismicity

Hydraulic fracturing processes have been reported to induce microseismic or microearthquakes events (Lopez-Comino et al., 2018). The general consensus among seismologist is that hydraulic fracturing does not induce felt or large/ devastating earthquakes (Majer et al., 2007; Holland, 2013; British Geological Survey, 2013; Atkinson et al., 2015. For example, the U.S. National Research Council report indicated that the process of hydraulic fracturing in most US states (especially in the Marcellus and Barnett shale plays) are generally accompanied by microseismicity of magnitude below 1 Mw, too little/ insignificant to be felt at surface, however, the injection of large volume of waste fluids in deep is associated with large earthquakes (National Research Council, 2012; British Geological Survey, 2013).

Shale gas development activity reported two seismic events near Blackpool in 2011 and operations suspended following public concerns (Fig. 31) (Clarke et al., 2014). Furthermore, earthquakes have been linked to shale gas activities along the Western Canada Sedimentary Basin in British Columbia at magnitude Mw 4.0 and Rocky Mountain House, Alberta, Mw 3.9. The highest seismic event recorded during hydraulic fracking was Mw 4.6 in British Columbia (Atkinson et al., 2015). Similar events have been noted in the Sichuan Basin (China), at magnitude of Mw 4.7, observed during injection activities, believed to be reactivation of major fault systems in the Basin (Lei et al., 2017). Instances of microseismicity (Mw 2.2) triggered by hydraulic fracturing have been reported in Harrison County and Poland Township (Ohio) (Friberg et al., 2014; Skoumal et al., 2015).

The monitoring of seismicity is essential during hydraulic fracking activities. Reports indicate that only 3% of the 75,000 wells hydraulically fractured in 2009 in the US were monitored for seismicity (Zoback et al., 2010). Figure 31 shows the record of microseismicity in the Barnett Shale. The profile illustrates the propagation of fractures during hydraulic fracturing activities and reports of negligible seismicity confined at deeper depths (5600 and 5900 feet subsurface) of the Ellenberger Limestone during hydraulic fracturing. No records of microseismicity at shallow depth have been recorded (Zoback et al., 2010).

Studies of seismicity related to hydraulic fracking and wastewater injection of 53 shale wells in Arkansas in 2010 showed that 50 % of the shale wells reported induced seismicity lower than M_L 0 (Yoon et al., 2017). In conclusion, the amount and level of induced seismicity triggered by hydraulic fracking activities vary significantly across geological terrain in terms of recorded events and the magnitude of seismicity. Studies by Clarke et al. (2014) found that the largest seismic events occurred or confined at the point of hydraulic fracturing down to several hundred meters below the zone of hydraulic fracking. Generally, hydraulic fracking operations induce weak microseismic signals that are difficult to detect with surface equipment.

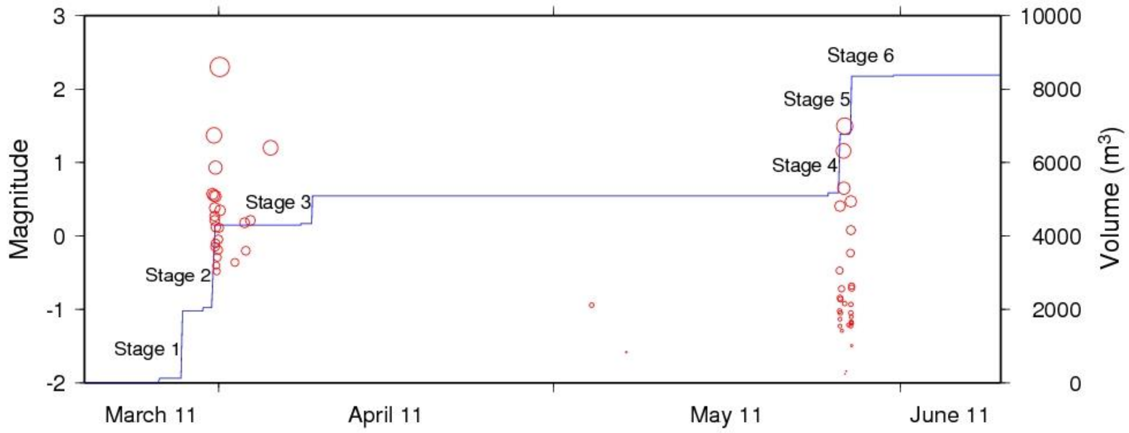


Figure 31. Injection Activity and Seismicity.

Source: British Geological Survey, 2013; Clarke et al., 2014.

Notes: Seismic events detected on regional seismic stations (> 80 km from the well) observed in the Blackpool Area. The volume of injected hydraulic fracking fluid (blue line) and magnitude of earthquakes (red dots). Largest earthquake activities relate after stages 2 and 4. The maximum event recorded was 2.3 M_L. Figures are not to scale.

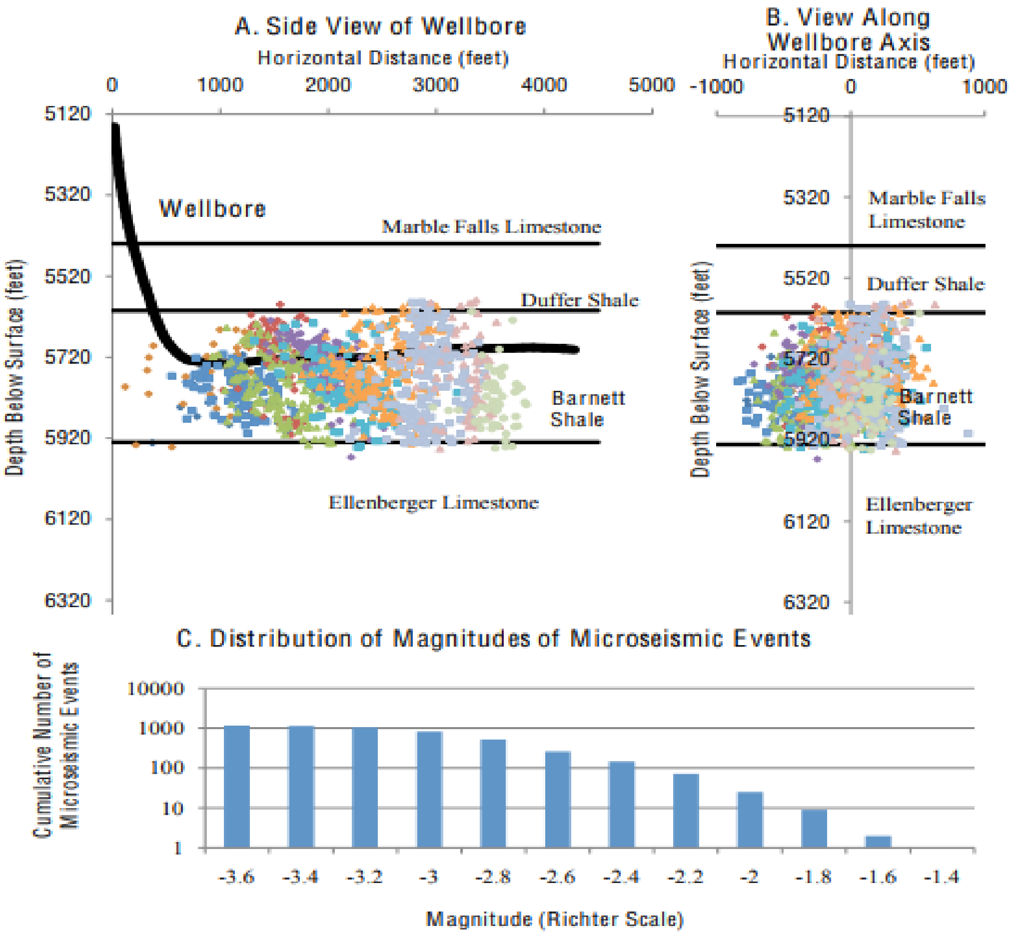


Figure 32. Microseismic Profile of Hydraulic Fracturing Operation in the Barnett Shale.

Source: Zoback et al. (2010).

Notes: The figure depicts hydraulic fracking operations undertaken in the Barnett Shale and seismic response. The points in A and B represents a microseismic event in each stage induced during hydraulic fracturing. C shows the distribution of the microseismic events by magnitude. Records of seismicity from hydraulic fracturing activities in the Ellenberger Limestone Barnett Shale showed very low seismicity at a shallower depth. Figures are not to scale.

Despite the record of induced seismicity by hydraulic fracking activities, studies suggest that the process pose very little risk of inducing major earthquakes (National Research Council, 2012; Royal Society and Royal Academy of Engineering, 2012; British Geological Survey, 2013). The Royal Society and Royal Academy of Engineering (2012) made the following recommendations as best practices to mitigate large scale seismic events during hydraulic fracking activities.

1. Detailed mapping of faults and application of relevant /geological information as baseline measurements to delineate areas of potential structural unconformities prior to drilling and hydraulic activities/ shale gas development.

2. Undertake minimal injection of fluid during hydraulic fracking operations and monitor seismic activities pre and post hydraulic fracking.

3.15 Analysis of Wastewater Storage and Disposal

In most countries where shale gas development is active, federal, and local regulatory authorities prohibit the excessive use of domestic water and discharge of wastewater directly to surface water bodies (such as streams, lakes, and rivers) without proper treatment (Fig. 33) (Kinne, 2018; Keiser and Shapiro, 2019). The application of forward osmosis, electrocoagulation, mechanical vapour compression, membrane distillation/separation, adsorption-biological treatment, and advanced oxidation methods complies with the sustainable requirement for water reuse, surface disposal and injection into the deep well (Sun et al., 2019). As discussed, the injection of large volume of waste fluids in deep wells has been found to be associated with large earthquakes (National Research Council, 2012; British Geological Survey, 2013).

Storage and transport of wastes are regulated under a range of health and safety laws to safeguard the environment from potential contamination. Studies have found that environmental risks are highest at the drill sites with elevated levels of effluent spills, leaks, flaring and air contaminants (Howarth et al., 2011; Olmstead et al., 2013; Rahm and Riha, 2012; Vidic et al., 2013; Vengosh et al., 2014). Therefore, improving the efficient treatment of wastewater and management of air containment is essential. In addition, continuous observations, supervising and monitoring at the wellsite may diminish the uncertainties of risks, contamination pathways and malfunctions of equipment during the development of the shale field.

Disposal of waste at the end of the life cycle present handling challenges. Storage of wastewater in containment/ manmade pond at the drill site for treatment and subsequent disposal is commonly adopted (Fig. 34). However, poor management of the pond through leaks (into the surrounding soil and land surfaces) and surface evaporation increases the concentration of air toxicity and biofouling (smell) of the additives/ chemicals. Trucking of waste from the site has been noted to increase the risk of accidental spills. Advances in fluid engineering design has produced cellulose and green fracking fluid to reduce the immense volume of water required for shale gas operations and safe disposal of the wastewater (Annevelink et al., 2016; Liu et al., 2021). Studies have shown that the lack of aquatic and aerial data at the drill sites and neighbouring communities hinders the validation of actual and predicted ecotoxic effects of the fracking chemicals.

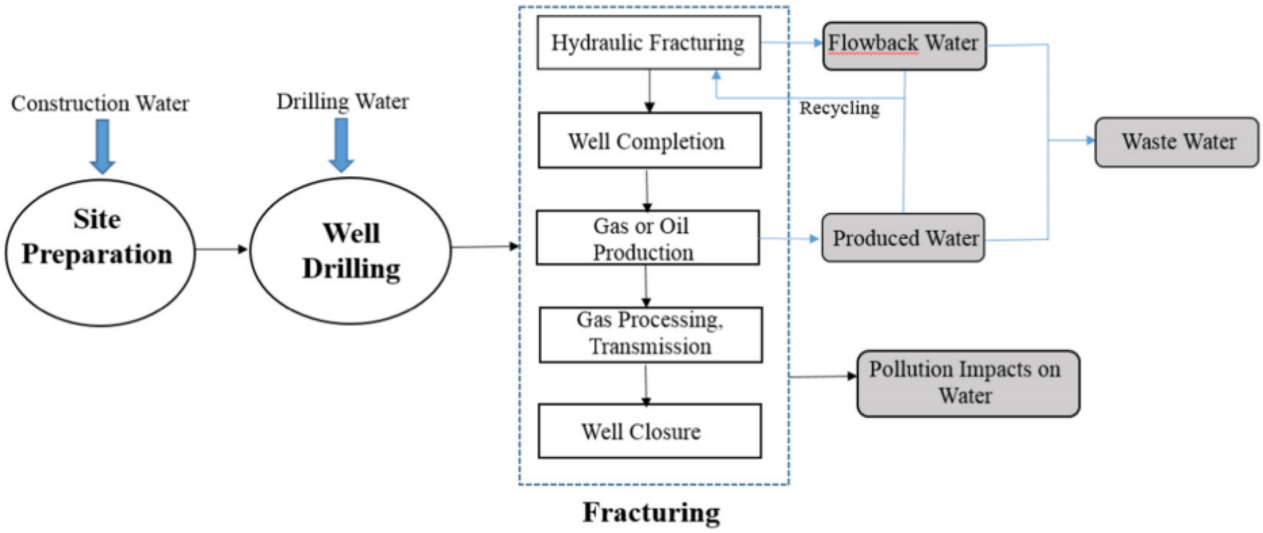


Figure 33: Cycle of Water Usage during Shale Gas Development.
Source: Mohtar et al. (2019).

3.16 Impacts on Land Use and Biodiversity

Several studies have explored the impact of shale gas development on land use and habitat loss (Fig.34) (Gilbert and Chalfoun, 2011; Drohan et al., 2012; Jones and Pejchar, 2013). In general terms, land use is defined as the conversion and management of land from one biome to another (Hansen et al., 2004). The growth of natural gas exploitation has been reported to increase the scale of land fragmentation. Considering the number of shale gas wells drilled in an area could lead to significant loss of forested habitat including the displacement of human and local wildlife (Moran et al., 2015). The allocation of land for shale gas development vary according to the density of well pads and the level of shale gas development.

Shale gas development involves a range of activities ranging from site preparation, roads, pipelines, and pad construction (Figs. 12 & 13). On an average, a shale gas well occupies 2.5 ha of land (Walton and Woocay, 2013, Souther et al., 2014). Moran et al. (2015) observed that loss of forested habitats has a long-term effect on the local ecosystem. Site preparation involves the removal of forest/vegetation cover including the excavation of soil from the area for road construction, space for storage tanks, other equipment, and pipelines (Olmstead et al., 2013; Moran et al. 2015. The footprint for pad construction is defined by the size of the pad, distance between pads and the number of clusters of wells on a pad (Drohan et al., 2012). The area occupied by buildings at the well site ranges between 1.2 to 9.9 ha of land (Fig. 34) (Baranzelli et al., 2015). Shale gas installations are commonly situated in remote locations and areas considered to be at the edge of sensitive/ protected habitat. It is worth noting that the licensed areas marked for shale gas development in the Karoo cover a total area of 236,400 m^2 host to sensitive and protected fauna and flora (Scholes et al., 2016). Studies by Wait, & Rossouw (2019) argued that a large proportion of the land licensed for shale gas development is used for extensive agricultural activities and livestock grazing. Therefore, the cost of land use and infrastructural planning (within the leased area) for shale gas development in the Karoo should be aware of the ecological impact. Milt et al. (2016) argued that operators and regulators can optimise the geometry of the surface land space and reduce the impact on the ecosystem by constraining the well pads and conservative surface layouts. Horizontal drilling activities permits multiple shale wells to be developed from one pad reducing cost and surface land space. Graham et al. (2015) argued that the influx of traffic and equipment to shale gas location increases the potential risk of traffic accidents, noise, and light pollution. The impact of shale gas development on the functional aesthetic landscape of the Karoo has also been documented (Timm Hoffman et al., 2021).

Figure 34: Shale Gas Development Site, West Virginia.

Source: Rogers (2013).

Ecological risks and potential impacts from well pad construction, manmade ponds and road development is comparable to other anthropogenic activities associated with surface mining, conventional oil, and gas drilling.

3.17 Effects on Nondisclosure of Chemicals

Transparency and disclosure-based principles are critical in policy decision making, corporate governance and gaining public support rather than information based on command-and-control practices (Solikhah and Maulina, 2021; Song et al., 2021). Disclosure of information and practices requires entities or bodies to release or provide access to information or elements of their products to the public and active stakeholders that are unavailable for them to make informed decision. The disclosure of information or product is motivated by the principle that the public has the right to relevant information to make an informed decision especially when the product is perceived as harmful to the environment and public health (Coliver, 2021). Studies have shown that disclosure of information may also influence companies to modify their behaviour and take protective steps to mitigate risks and uncertainties (Fetter, 2017). In addition, non-disclosures on processes and products have been found to reduce public confidence and support. Lonnquist and Gallagher (2021) argued that the non-disclosure and protection of proprietary information hinders public access to relevant information about the potential risks of chemicals used for hydraulic fracking.

3.18 Conclusion

Studies shows a range of environmental impacts caused by shale gas development. Emerging empirical studies indicates gaps in knowledge to confirm the level of impacts on the environment. However, the shale industry is evolving rapidly (technologically) with best practices aimed at mitigating potential environmental risks induced by shale gas development. Impacts of shale gas development on the Karoo ecosystem is uncertain and probable, given the lack of experience, weak regulatory laws, and policies required to govern the shale industry, applying the precautionary principle seems plausible in the Karoo. The review of literature in this study demonstrates the weight of evidence and risk assessment in order to prioritize future studies in these areas and establish empirical basis for policy making.

Finally, this study demonstrated that all sources of energy development and industrial processes have some level of environmental impacts on society therefore, public judgement concerning the level of impact of shale gas development and trade-offs are more value decisions that should encompass empirical results.

Chapter 4: The Economic Impact of Shale Gas Development

4.1 Introduction

Although fossil fuel is a finite resource, the production of fossil energy continues to dominant the global energy landscape (Kraemer and Stefes, 2016). There is no doubt regarding the effect of fossil energy on climate change. The consumption of fossil fuel constitutes the largest contributor to greenhouse gas emissions and because the development of fossil fuel leaves a large footprint on our ecological system, the need to transition to a greener future is imperative. Over the last decade, natural gas is beginning to receive a growing attention as people become aware of sustainable energy development. Studies have highlighted that transforming from a carbon-intensive economy is the solution to climate change and declining global economic growth. Investment in sustainable energy development will not only influence the vibrancy of global economic growth but also shape the future of the world. Growth in global human population is driving significant demand on global energy consumption. The IEA stated that by 2040, global demand of energy is projected to increase at 48 % (Conti et al., 2016). In light of these, governments are diversifying their domestic energy portfolio and seeking alternative energy options to satisfy growing demand and also mitigate the effects of climate change. This explains why the many countries including the government of South Africa is supporting the development of shale gas in the Karoo and simultaneously increasing the share of domestic renewable energy.

Natural gas has many benefits, it is the cleanest fossil fuel and cheap to produce reducing foreign energy dependent. The multiplying effects of shale boom may present significant opportunities and benefits to the local arena, such as lower prices for domestic use and manufacturing sectors. However, the longer-term effects of shale gas development on the economy are unknown but may be complex. Literature on the longer economic impact of the shale boom is limited however, studies by Brown (2014) did not find evidence of the resource curse for local economies. The study reported positive earnings and employment effects during development and bust cycles.

A study found that shale gas development added over $380 billion and 2.8 million jobs to the America economy by 2035 (Aguilera and Radetzki, 2014). However, the future of shale gas development is uncertain given that a large number of shale wells are required to achieve commercial success. Opponents of shale gas development can’t conceive how to make the transition or switch from traditional energy sources at cost that are sustainable. Additionally, there are growing concerns whether predicted costs of shale gas development and value to the local economy in terms of job creation and impact on local GDP are widely exaggerated or over estimated. The inconsistencies in projected benefits and risks are attributed to differences in scenario planning, sustainable goals, and economic models. The economic competitiveness of shale gas in the new energy landscape is still in question given that the cost of electricity generation and distribution of renewable energy in certain region is cheaper due to provision of government subsidies.

South Africa is in the early stage of exploration activities in the Karoo Basin. To date, no shale well has been drilled in the Karoo Basin due to the moratorium invoked on exploration of shale gas activities in the Karoo Basin. Proponent of the shale industry argued that the moratorium is harmful to the future of the country as it seeks to move forward in the transition pathway.

However, the cost of developing the Karoo shale resources including the long-term impact on the future geo- economic landscape of South Africa are uncertain. Studies have demonstrated the potential and sustainable way to develop the South Africa shale gas industry, given lessons learnt from shale gas development in the US and elsewhere. Furthermore, studies have shown that the US experiences cannot be generalized to the South Africa context. Nevertheless, this study sets the extent to which generalization can be made beyond the US shale gas industry.

Literature is replete with studies focused on the long-term sustainability of shale gas development; however, these studies provide a narrow perspective of the shale gas industry without contextualizing the discourse. This current study presents a multidisciplinary perspective and situational context of shale gas development that may demonstrate the broader economic impact in South Africa. Given the significant transformation and market dynamics of the shale industry in the US sets the basis of shale gas development in South Africa. The extent to which the US shale boom is transferable to the South Africa context will be different given the disparities in geology, social context, best practices, laws/ regulations, mineral rights, market conditions, technical expertise/ technologies, infrastructural development.

4.2 Impacts on the Global Energy Market

The dramatic growth in shale reserves is playing a critical role in meeting global energy needs (Fig. 35). The success of the shale boom and its transformational benefits in the US has further raised the prospect for shale gas development in other countries. Given the growth and global demand for natural gas, it is projected that unconventional gas will displace coal by 2035 (Fig. 35) (IEA, 2019). It is projected that the development of shale gas could contribute approximately 7,299 tcf to the global reserve of natural gas surpassing projected conventional gas reserves at 6,614 tcf (Cooper et al., 2016). The global LNG outlook and existing unconventional projects is expected to increase at 2.6 % per annum until 2025 (Jackson et al., 2019). An important consideration for this growth is based on the fact that natural gas is flexible (it can be ramped up quickly to compensate for market volatility and energy demand), it is also traded in a variety of variety of financial and physical contracts and commodities such as over-the-counter active trading, long term optimistic futures markets, exchange-traded funds (ETF) or contract for difference (CFD) formats (Henderson and Moe, 2019; Højlund and Nielsen, 2019; Li et al., 2020). It is also worth stating that over 70 % of natural gas is traded on long term contracts, converted as liquified natural gas (LNG) for external exports/ markets to safeguard the security of energy supplies. For instance, South Korea and Japan (Asian markets) depend wholly on LNG imports compared to the UK rely on 55 % of LNG imports, 45 % of UK gas demand is produced locally (EIA, 2019b; IGU, 2019; Jackson et al., 2019). The wellhead price of natural gas varies based on volatility of price and global demand, logistics cost, market/ economic factors, geopolitical and weather/ seasonal conditions. Caporin and Fontini (2017) found significant volatility in natural gas prices caused by significant contribution of US shale gas development to the global gas market. The United States, Canada, China, and Argentina are the only countries producing shale gas at a commercial level even though 41 countries have a huge reserve of shale resources (Fig. 1) (Shcherba and Vorobyev, 2018). Most of the countries are at a different stage of evaluating the prospect of developing their shale reserves in a sustainable way, most bans or moratoriums on shale gas development have come from European countries (Germany, France, and Bulgaria) given the uncertainties and risks surrounding shale gas development, nevertheless, Poland have moved further to develop their shale resources. Given strong public opposition, in 2011, the government of South Africa placed a moratorium on exploration licenses the Karoo shale resource (Andreasson, 2018; Le, 2018). The economic viability of the Karoo shale resource can only be assessed and proven through exploratory drilling activities requiring that the moratorium is lifted. Even if testing of the shale reserves proof that the Karoo shales are economically viable, several structural factors make it challenging to develop the Karoo reserves. Firstly, the Karoo shale basin is remotely domiciled from existing industrial and transport infrastructure which has the potential to prolong development efforts and also ramp up the cost of developing the Karoo shales. Secondly, the regulatory framework of unconventional gas development is poorly characterised and laden with bureaucratic irregularities.

The legacy of environmental impacts caused by shale gas development in the US, combined with the lack of scientific/ public consensus as to the exact nature and degree of the impacts and benefits associated with the shale technology has further undermined public confidence and trust regarding the future of shale gas development in the Karoo (Andreasson, 2018). Public concerns in South Africa have not only focused on water requirement for shale gas development, air quality impact, health impact, potential contamination of the surface environment and damage to the fragile Karoo biodiversity but also potential negative economic impact. Opponents argued that shale gas development will crowd out the local economic activities, out compete investments in renewable energy and disrupt the fragile social fabric of the Karoo community, therefore unsustainable in the current context (Willems et al., 2016; Andreasson, 2018; Issah and Umejesi, 2019). The need to mitigate global warming through clean and efficient energy supplies is driving environmental and energy policies in countries like South Africa to maximize the advantage of alternative energies sources and accelerate the transition from high carbon economy to sustainable energy. The adaptation of climate change policies puts shale gas development at the forefront of alternative energy development in South Africa (IEA, 2020).

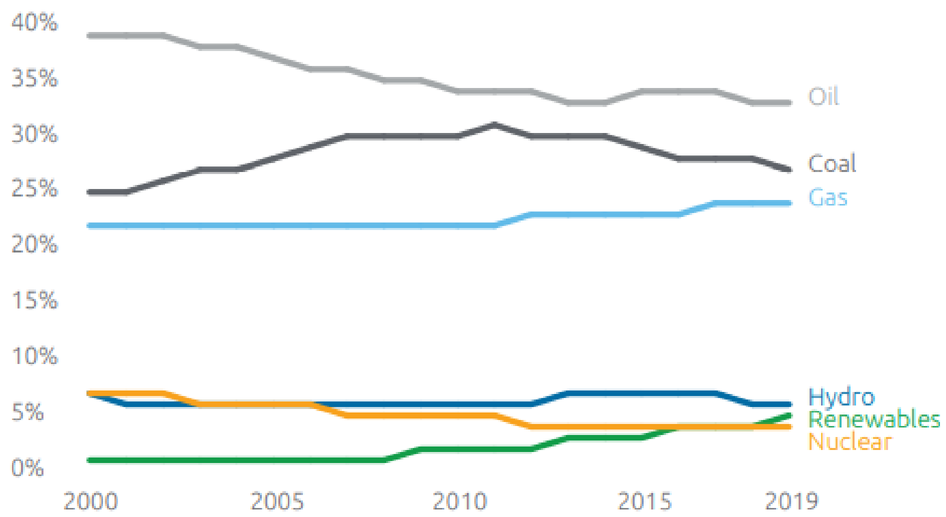


Figure 35: Evolution of Primary Energy Mix and Power Generation.
Source: Global gas report (2020).

4.3 Impact of the COVID-19 Pandemic on Natural Gas Development

The impact of COVID-19 pandemic meant an accelerated depreciation of shale assets and poor capitalisation of projects (Fig. 36). Prices of natural gas fell by 3.3 % during the pandemic due to low energy demand, rising questions if the shale boom can be sustained given the vulnerability of gas prices and energy demand, growth in renewable energy increased by 6.1 % over the pandemic (IEA, 2020). The IEA forecast accelerated growth in energy development in the last quarter of 2021 driven by global economic recovery and increase in industrial activities. A long-term recovery is likely to spur growing demand for natural gas characterized by market driven conditions, geopolitical considerations, and policy changes (IEA, 2020).

A sustained cycle of lower gas prices in the major gas markets indexed by the Covid 19 pandemic coupled with reduced financial incentives for conventional fossil fuel exploration is responsible for driving the transition/ switch to unconventional gas development (Van de Graaf, 2020). The emergence of LNG exports from North America to the Asia markets has further pushed low gas prices with persistent over supplies from Russia and Australia. Importers of natural gas can now deal with lower LNG prices relative to crude prices (Barbosa et al., 2020; IEA, 2020).

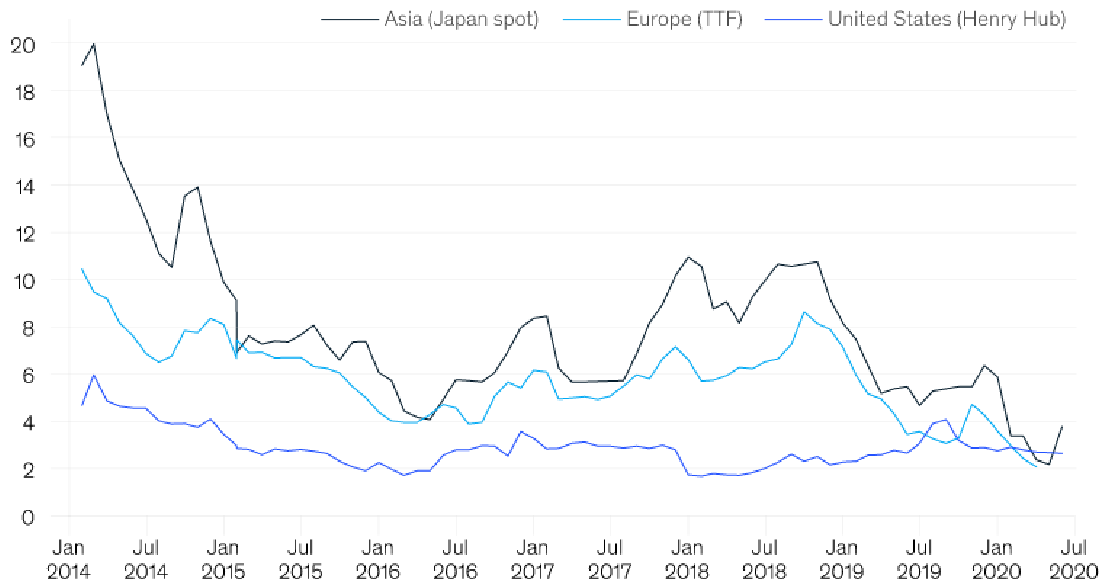


Figure 36: Gas Prices $/MMBTU in Selected Markets.
Source: Barbosa et al. (2020).
Notes: The figure shows the convergence of gas prices.

Countrywide lockdowns and diminished industrial activities have contributed to oversupplies and lower gas prices over the last quarter of 2019 to 2020 continuing into 2021 (Fig. 36).

Additional uncertainties are projected regrading growth and prospect for shale gas development and job creation depending on how the pandemic impact gas markets in 2020/21 including impact of climate change policies, natural gas demand is projected to drop by 4 to 7 % and further fall in spot natural gas prices setting a possible convergence of gas prices (Fig. 36) (the US, European and Asian prices) (Mohammed and Barrales-Ruiz, 2020; IEA, 2020).

The energy supply and baseload for domestic heating and cooking using natural gas in most developing economies including South Africa is low (3 %) in the energy mix (World Bank, 2014; FAO, 2017; Nathaniel et al., 2019). The use of wood and coal constitute an important source of residential heating and cooking in South Africa, which constitute is a substantial contributor of ambient air pollution and source of human health such as cardiovascular and respiratory problems. Studies indicate the inherent challenges to tackle emissions from biomass heating without addressing the source of pollution from a sustainable energy perspective (Dagnachew et al., 2020). A rapid transition/ fuel switching from coal and biomass heating could make the supply of clean energy more justifiable to rural population who are challenged by poor power/electricity distribution in the Karoo.

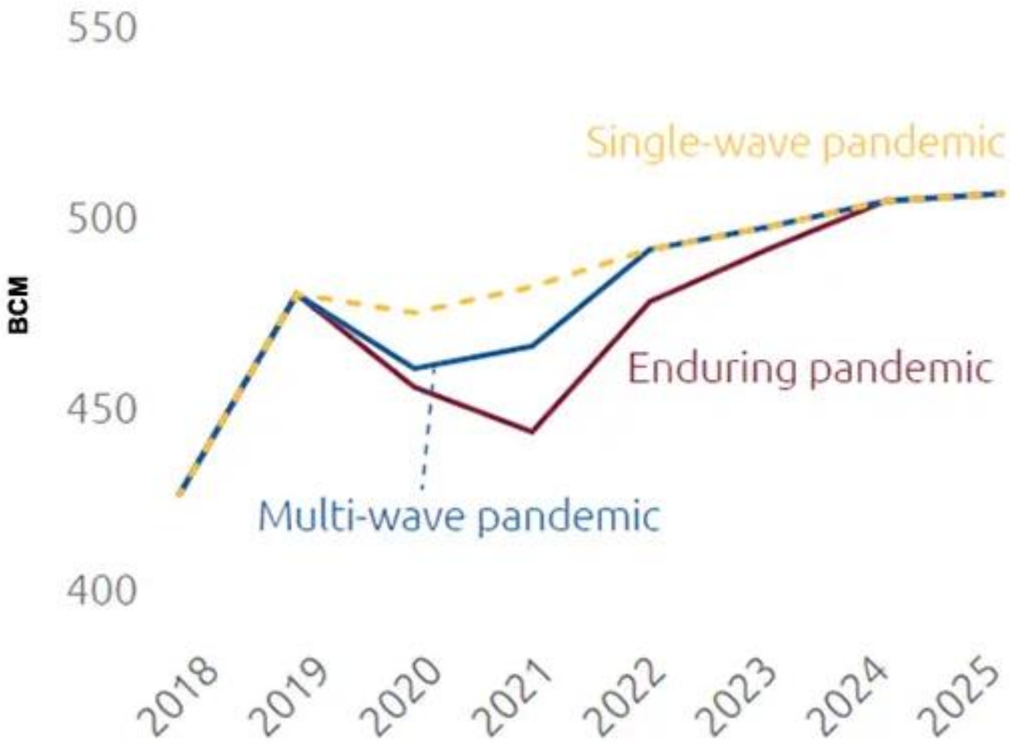


Figure 37: Global LNG Demand under Multiple Covid 19 Pandemic Scenarios.
Source: Global Gas Report (2020).

4.4 Natural Gas in Southern Africa

South Africa natural gas landscape started with the partnership of Sasol (synthetic fuel industry) in Sasolburg and Secunda in the 1950s and ’80s. The South Africa LNG landscape include import from the Pande and Temane gas fields from Mozambique using the ROMPCO 865-km pipeline commenced as part of the diversification of South Africa economy from coal power (Van Zyl, et al., 2016). The utilization of natural gas in South Africa is less than 4 % of the primary energy base with coal dominating more than 90 % of the energy mix (Fig. 38) (IEA, 2020). Diversifying the primary energy base from coal power to clean energy has many benefits but the socioeconomic implications of the transition need to be carefully managed including the restructuring of infrastructures and reforming the national energy body ESKOM.

In terms of policy indicators, the National Development Plan 2030 set a clear policy agenda for sustainable energy development, decommissioning the 42 GW of coal-fired local energy systems, and promoting an additional 20 GW of electricity generation from natural gas and renewables by 2030. The IEA projected that the South Africa economy could double by ramping the share of natural gas and renewable energy (solar and wind) into the primary energy mix (Van Zyl, et al., 2016; IEA, 2019). The derivatives of natural gas constitute a critical component for production of liquid fuels, ammonia, wax, and methanol. The 2019 Integrated Resource Plan (IRP) establishes key considerations and the framework for energy development that incorporates natural gas into South Africa energy mix. The IRP forecast a 14 % contribution of natural gas to the supply of the energy base (Van Zyl, et al., 2016). However, the IRP does not optimise the just transition beyond 2030 which makes it long term planning and adaptation vulnerable to disruption.

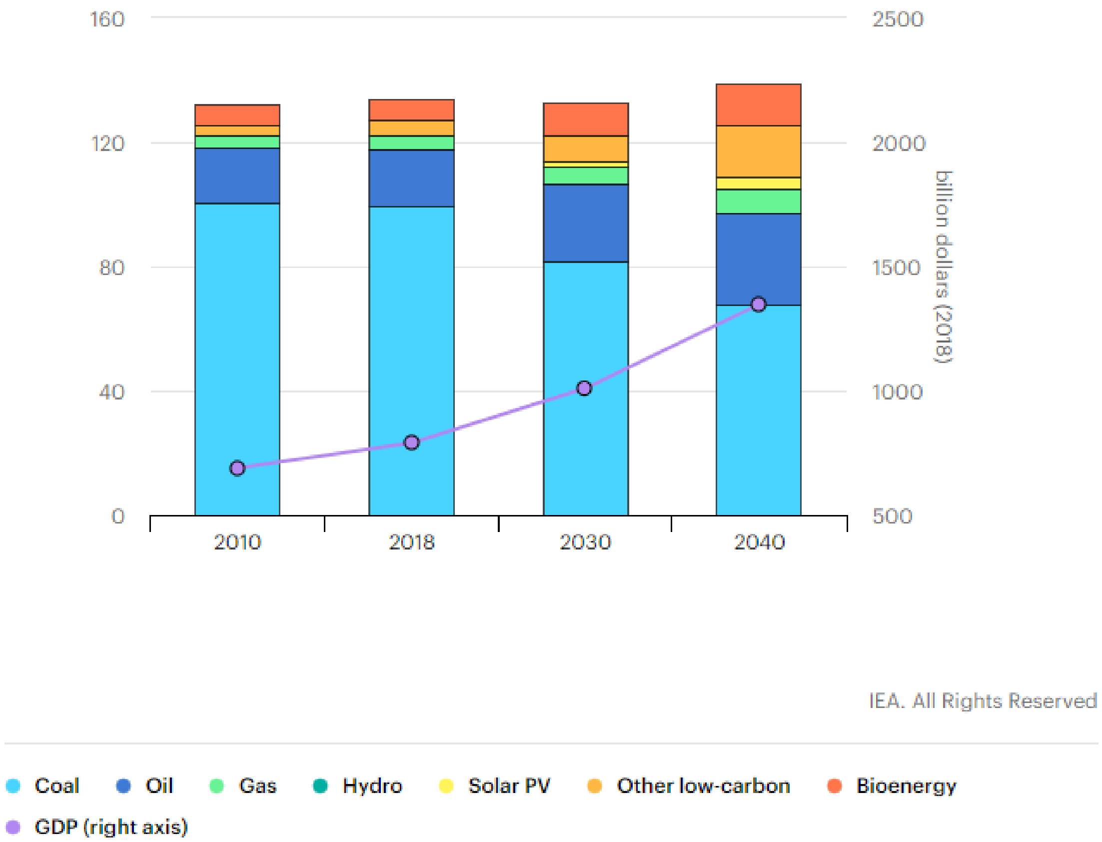


Figure 38: South Africa National Energy Demand and GDP 2010-2040.
Source: IEA (2020).

4.5 Rationale for Shale Gas Development in South Africa

South Africa is striving to develop an inclusive and sustainable economy, mitigate local CO_2 emissions, create jobs, improve energy security, and tackle the issue of energy crises in the country (Alden and Le Pere, 2009; Andreasson, 2019). However, there are increasing public concerns about the size and prospect of Karoo shale gas deposits. The US shale boom demonstrated profound economic benefits in the US including the creation of over 600,000 jobs and projected to increase to over 1.6 million jobs by 2035 and forecasted GDP growth of US$231.1 billion by 2025 under pre Covid conditions (Wang et al., 2014; Andreasson, 2019).

The democratisation of South Africa in 1994 and subsequent lifting of economic sanctions, population growth and scale of industrialization spurred significant economic growth in South Africa and energy demand, placing enormous pressure on the coal-fired stations to generate electricity (Pretorius et al., 2015; Andreasson, 2019). Shortage in energy supply is also reflected in the rising cost of electricity tariffs and structural inequalities in electricity distribution across the local population (Greenberg, 2009; Alton et al., 2014). The precautionary position taken by the South African government in developing the Karoo shale reserves provides a logical pathway to a new green future, advance a low-carbon economy, create jobs, achieve energy security, and make affordable electricity accessible to the growing population.

Studies have shown that shale gas development could add over 700,000 jobs to the South Africa economy and stimulate the country GDP by R200 billion annually (Econometrix, 2012; Hedden et al., 2013; Wait & Rossouw, 2019). Given South Africa's dependence on coal power, a transition to natural gas presents a viable option from high carbon fossil fuel to renewable energy because of the operational flexibility of natural gas. It is not entirely clear the position of coal power in the transition and the impact on coal jobs, given that employment in the coal industry constitutes a significant aspect of the South Africa economy. Andreasson (2019) highlighted that striking a balance in the confluence of political powers is required to move the industry forward.

4.6 Analysis of Economic Feasibility

The development of shale gas offers considerable economic opportunities for South Africa. The development and future of the shale industry in South Africa is uncertain given the significant uncertainty regarding the true commercial size of the Karoo basin (Fig and Scholvin, 2015; Chapman et al., 2016). The economic potential of the Karoo basin is worth exploring but the future of the industry depends on positive market externalities and a range of geological and social factors.

Shale gas development has been underway for decades, national and global estimate of shale reserves has been revised several times following discovery of new shale plays and availability of production/ geological data. For instance, in 2012 the EIA revised the resource potential of the Marcellus Shale basin from 827 tcf to 482 tcf (US EIA, 2012). Building on this, a positive outlook for shale gas development in South Africa must be large enough to attract potential investment to fully explore and develop the Karoo basin (Hausman and Kellogg, 2015; Gamper-Rabindran, 2017; Tietenberg and Lewis, 2019).

In 2010 the South Africa government commissioned the econometric studies to evaluate and build the outcome and benefits of contingent shale resources in the Karoo. The econometric model relies on two contingent scenarios of resource development 20 tcf (base case) and 50 tcf (optimistic/ high case), respectively (Econometrix, 2012) (Table 12). Along the same line, Wait and Rossouw (2014) put forward an economic impact model which provided lower employment opportunity should shale gas development move forward (Table 12). There is an argument that the Karoo shale resource is over estimated, and the benefits exaggerated given the geological complexities of Karoo, market volatilities and geopolitical uncertainties. Kay (2011) explored the case of resource overestimation in the Haynesville and Barnett Shales and argued that resource estimates in this basin exceeded actual production profile. This creates an exaggerated estimate of economic benefits should development move forward, this can lead to excessive budgeting and spending with long term consequences during the bust cycle (Kinnaman, 2011; Rousu et al., 2015). Studies have also demonstrated that benefits from shale gas development do not filter to the local community such as direct royalty payment/ leasing of mineral rights to local people - landowners (Kay, 2011; Hardy and Kelsey, 2015). In addition, studies have proven that the majority of the private beneficiaries/ landowners or owners of mineral rights in the US do not reside in the local community and the extent in which beneficiaries reinvest the benefits in the local community is uncertain (Van Zyl et al., 2016). It is worth nothing that landowners in South Africa do not own mineral rights, resource ownership is owned and governed by the state. The extent to which the US shale boom can be replicated in the South Africa context is uncertain, a range of factors appeared to be limiting the prospect such as the complex geology of the Karoo Basin, weak regulatory/ governance structure, social acceptability is low, existing supply chain and infrastructure development is non-existent, skilled human capital is lacking. Given these limiting factors, replicating the US shale boom in South Africa is unlikely to occur in the short term.

Table 12: Economic Models and Impact Analysis

Category	**Econometrix (2012) Static Model**		**Wait & Rossouw (2014) Dynamic Computable Equilibrium (CGE) Model**	
	20 tcf	50 tcf	Scenario 1	Scenario 2
Potential life of resource (years)	25	25	25	25
Potential contribution to GDP (%)	3.3	9.6	3.5	6.9
Potential contribution to GDP (ZAR bn)	35	90	26	52
Ave production per year (tcf/yr)	0.8	2	0.8	2
Timeline	2035	2035	2-3 years	2-3 years
Potential permanent employment	300, 000	700,000	1441	2471

Source: Wait & Rossouw (2014).

The EIA estimated that the Karoo Basin contained 390 tcf of unproven gas reserves while the South Africa Council of Geosciences and Petroleum Agency put the estimate at 36 tcf (EIA, 2013).

Table 12 presents a broad comparison of the Econometrix report funded by the South Africa government and the study undertaken by Wait & Rossouw (2014). Both studies present significant variations of jobs creation with similar projected volumes/ production of shale gas are assumed. The difference is attributed to the economic models used in the analysis by both studies. Shale gas development is projected to create 300,000 jobs and expected to generate approximately ZAR 30 to 90 Bn in economic activity over a period of 25 years forecast. This projection includes direct and indirect activities generated by the supply chain and other multipliers in revenue, tax, and profits.

4.7 Scenario Analysis

The IF model forecasts an energy future based on historical trends of shale gas production in different environments, incorporating existing energy and climate policies. However, the model does not account for policy shifts in energy development and exogenous factors related to global market conditions. In both cases, the Boom and Blue Bridge scenarios forecast a reduction in coal production beyond the year 2030, cumulating in a significant reduction in carbon emissions. Hedden et al. (2013) utilized the International Futures (IFs) integrated system to facilitate and model the outcome of scenario development and outcome of shale gas development in South Africa, noting the short and long-term impacts of energy production scenarios as they relate to natural gas, coal, nuclear energy, and renewable energies goals.
Figures 39, 40 and 41 illustrate the possible scenarios:

1. **The 'Base Case'** analysed a situation where shale gas development holds the least economic potential with insignificant environmental and social impact on the Karoo (Fig. 39). Total energy production is projected at 1.88 billion BOE with carbon emissions below 5.36 billion tons. The Base Case provides the basis that shale gas development will not proceed further. In this scenario shale gas development is not economically viable, wells are plugged and abandoned. The supply of national energy is supported by LNG import (Scholes et al., 2016).

2. **The 'Boom Case'**/**Small Gas** forecasts a commercial production of natural gas, with immediate and future gains in job creation, a significant boost to economic growth and security of energy supplies (Fig. 40). In this context, the Boom scenario emphasizes significant environmental and social risk, especially at full-scale development of shale gas resources. The total energy production for the Boom Case is 2.52 billion BOE, with no significant reduction in the total carbon emissions at 5.35 billion tons. Although the result from this scenario is small but reasonably viable with 5 Tcf of natural gas produced from a 30 x 30 km production block consisting of 550 wells on 55 well pads (Scholes et al., 2016).

3. **The 'Blue Bridge'/ Big Gas** scenario describes a situation where shale gas is developed economically with the least socio-environmental impact (Fig. 41). The Blue Bridge scenario attracts minimal tax on shale gas development, which is invested in developing renewable energies. The total energy production projected for this scenario is 2.94 billion BOE with a significant decline in carbon emissions at 5.11 billion tons. This model forecast a large discovery of approximately 20 Tcf produced from 4100 shale wells consisting of 410 well pads across four production blocks (Scholes et al., 2016).

Hedden et al. (2013) suggested that carbon tax could be levied on hydraulic fracking in the Boom and Blue Badge scenarios which are invested in moving the transition to renewable energy. The Boom and Blue Badge scenarios present a scalable opportunity for investment in renewable energy - in the energy mix and improve the long-term sustainability agenda of South Africa.

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Figure 39: Base Case Scenario.
Modified from Moyer et al. (2013).

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Figure 40: Shale Boom Scenario.
Modified from Moyer et al. (2013).

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Figure 41: Blue Bridge Scenario.
Modified from Moyer et al. (2013).

4.8 Economics of Gas Production

Geological studies have demonstrated the distinction between conventional and unconventional natural gas development. Unconventional gas production is a complex engineering process that requires horizontal drilling and hydraulic fracking (Kim et al., 2017; Milkov et al., 2020; Wang, 2020). Decline curve analysis (DCA) is the most common technique to forecast production rates of oil and gas from historical production trends of reservoirs (Jamshidnezhad, 2015). However, significant misinterpretation exists bordering on decline curve analysis of shale wells (Wang, 2020). For example, early exploration work in the Barnett shale was thought to be uneconomical but showed significant prospect in the latter phase of development. The Barnett is one of the biggest shale gas resources in the US (Fig. 42 and Table

13) (King, 2010; Manning, 2014; Wang, 2020). Geologists are able to identify" sweet spot" from logs and cores retrieved from shale wells in order to characterize the prospectivity of the shale play. The increase in investment is driven by favourable geological results as the basin progressed to field development program. The development phase not only produce gas but also help to sustain/ create jobs across the supply chain. However, not every shale well is economical or maximise significant production to guarantee positive investment decision for field development. The production of shale gas is characterized by early flush activities followed by rapid flow through the fractures (Fig. 43). The expected ultimate recovery (EUR) of gas produced by the early flush in the first year of production ranges from 30% to 50% proven to be viable for development. Subsequent production has been shown to decline in flow rates but proven economical building a base for gas production (Fig 42) (King (2010; Aucott et al., 2013; Baihly et al., 2015). King (2010) indicated that 80% of the shale wells produced between 2001 to 2007 in the US were economic under prevailing gas prices at $10 per mcf. However, subsequent fall in gas prices including cost/ CAPEX optimisation in drilling and completion activities created conditions to move field development forward.

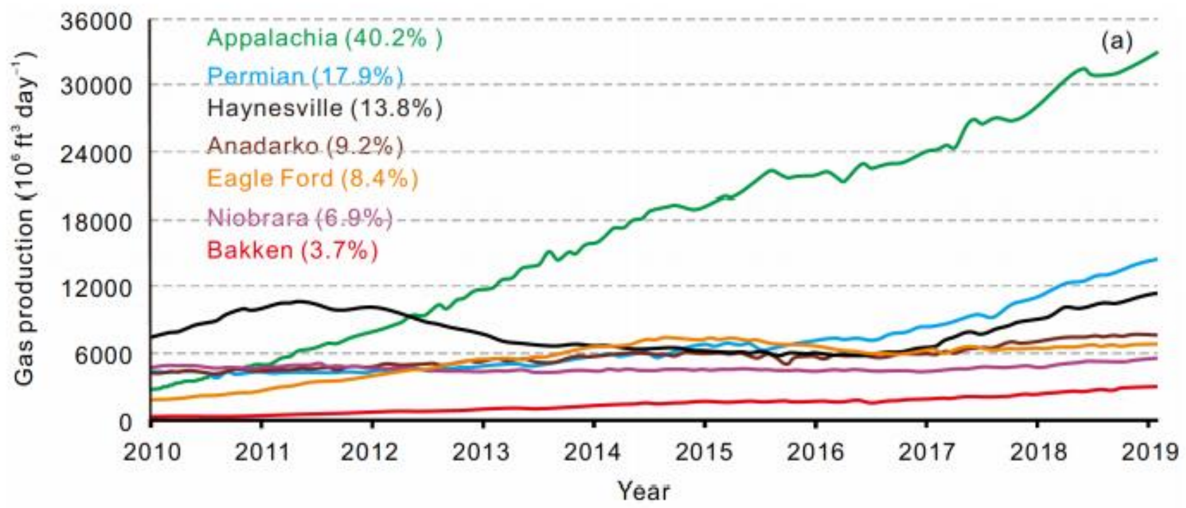

Figure 42: Average Production per well for Major US Shale Gas.
Source: Hughes (2014).

Table 13: Decline in Production Rate of Major Shale Plays in the US.

Shale Play	Average 3-Year Well Decline Rate (%)	Average First Year Field Decline Rate (%)	Optimism Bias Rating of EIA's Forecast
Barnett	75	23	Very High
Haynesville	88	49	Very High
Fayetteville	79	34	Very High
Woodford	74	34	High
Marcellus	74-82	32	Reasonable
Eagle Ford	80	47	Very High
Bakken	81	41	Conservative

Source: Hughes (2014).

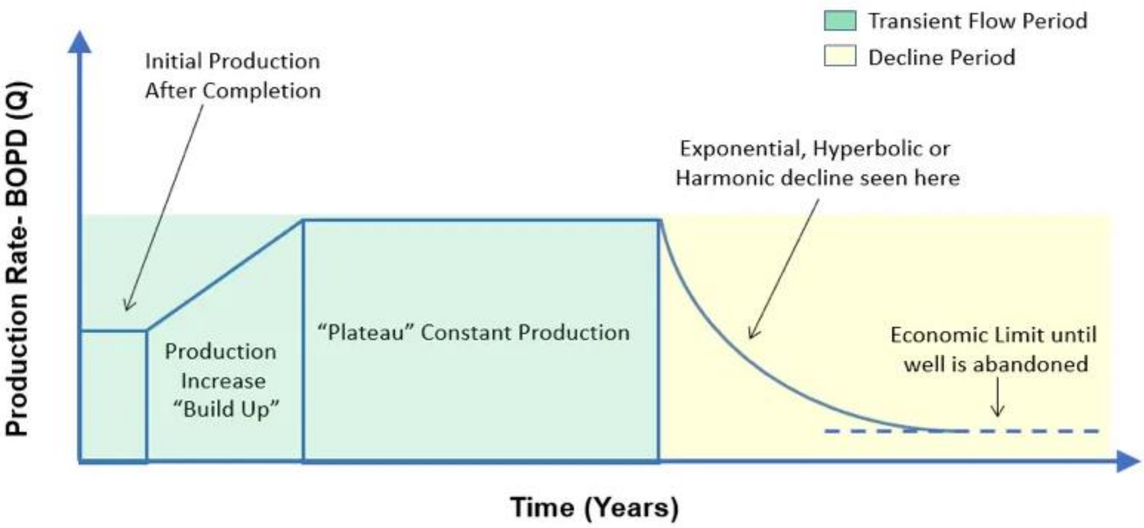

Figure 43: Transient Flow of Shale Wells
Indicating pressure drawdown, and build-up analysis

Source: Oil and Gas Decline Curves - Rock River Minerals (https://www.rockriverminerals.com/knowledge-center/oil-and-gas-decline-curves/)

Figure 43 illustrate the transient flow period and initial production phase of gas production when no reservoir barriers have been breached. The transient flow period is characterized by a steady reservoir pressure. The decline curves analysis is applied after the shale wells reached the 'plateau'. In most 'shale plays' the transient flow may be limited/ short resulting in rapid declines in well productivity after the first cycle. Recovery of the gas-in-place after the initial phase is much lower than conventional oil and gas, between 20–30 % (Kaiser, 2012).

4.9 Drilling and Well Cost

Cost for shale wells vary across the major shale fields in the US and ranges between $2 to $10 million per well (Table 14) (EIA, 2012; Saussay, 2018). Given the current economic trend is unfavourable for exploration, the EIA projects a recovery of oil and gas activities in 2022 providing the opportunities for new entrants of shale producers (Fig. 44) (US EIA, 2021). The cost of domestic rigs accounts for 25% of the cumulative well cost and has stabilized in the current market scenario improving CAPEX and moderate investment approach of shale gas development. The changes in related costs and technological improvement allows shale gas fields to be developed sustainably with fewer drilling rigs (Apergis et al., 2021).

However, the cost of drilling a shale well in the US cannot be applied directly to the Karoo Basin given that the geological terrain and prevailing local market scenario are uniquely different. However, the Karoo shale deposit (Ecca Supergroup/ Whitehill Formation) have been identified in strata > 4921ft/ 1500m comparable to Marcellus and Fayetteville depth (Table 14) (EIA, 2013). Therefore, drilling cost in the Karoo Basin may be lower than the US shale basins (assuming optimal hole conditions including the availability of domestic drilling rigs, drilling equipment cost and supply chain) (EIA, 2014). There is significant unpredictability in the success factors which could have a substantial impact the sensitivity and local analysis of shale gas development in South Africa (Clark et al., 2021). Given the key uncertainties and geological risks, the chance of commercializing a new shale play is significantly low, however, drilling cost can be reduced to make shale wells produce at economic rate. Aguilera (2014) argued that the higher cost of developing the shale reserves is uneconomically at a high breakeven price of $20 per thousand cubic feet (mcf) assuming Asia gas price at $12 or $18 per mcf.

From a reservoir engineering perspective, Lee et al (2011) and Browning et al (2013) argued that the production capacity of a shale well could be enhanced by a factor of 10 depending on the characterization of the geology/ reservoir formation and improved technological capability. However, shale gas development requires an intensive drilling campaign to maintain commercial levels. For example, shale plays in the US required an average of 1,087 active drilling rigs per year to achieve economic shale gas production (Spencer et al., 2014). Based on available data from shale plays in the US, Baihly et al. (2010) estimated EUR of a shale well ranges from 1.4 BCM to 5.9 BCM. If similar gas recoveries are forecasted for shale gas development in South Africa will require 164 to 714 shale wells for every 1 TCF of gas produced (Davies et al., 2014). Similarly, Gény (2010) revealed that 30 bcm production of shale gas per year would require active drilling of an average of 700 to 1000 shale gas wells per year over several decades. In addition, labour cost and readiness of an experienced and skilled workforce are likely to post a cost and scale constraint for extensive shale gas production in the Karoo (Spencer et al., 2014).

South Africa human capital and infrastructural development for shale gas development are limited (Fig and Scholvin, 2015). Table 15 outlines five areas that are significantly challenge the development of shale gas in South Africa. Most importantly, resolution of the uncertainties surrounding shale gas development in the Karoo requires extensive investment in stakeholder engagement in order to secure SLO in the Karoo (Landsberg and Qobo, 2017; Andreasson, 2018). Several studies have identified the challenges in developing the Karoo shale play (Chapman et al., 2016; Landsberg and Qobo, 2017; Andreasson, 2018).

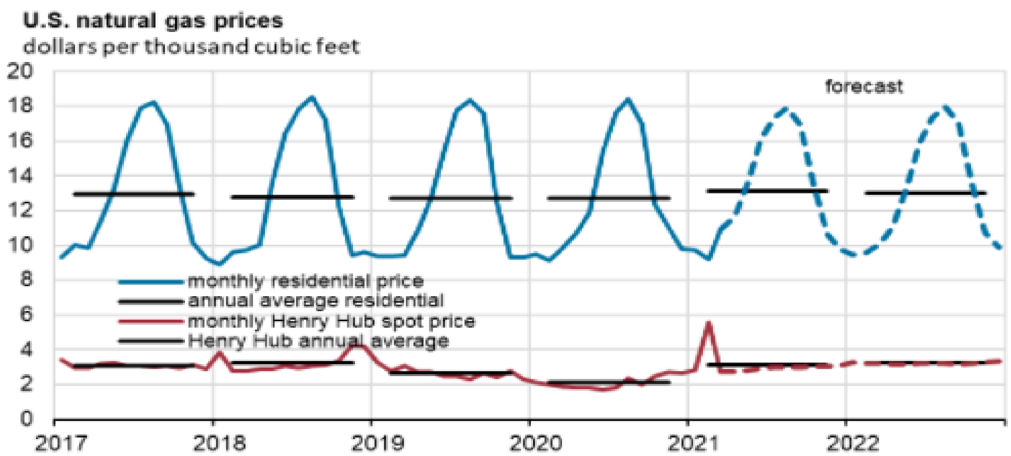

Figure 44: Short Term Energy Forecast (Post Covid-19)

Notes: showing natural gas prices
Source: US EIA, Short Term Energy Forecast, April 2021
https://www.eia.gov/outlooks/steo/

Table 14: Average Drilling Costs and Depth of US Shale Plays.

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Source: Modified from Saussay (2015). Notes: Tables shows that the average cost of shale well increases with depth.

Table 15. Regulatory Challenges Impacting Shale Gas Development

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Source: Modified from Mares (2013).

4.10 The Benefits of the Shale Revolution

Several studies have highlighted the benefits of the shale boom in terms of enabling economic growth, job creation and ensuring security of energy supplies and independence. The effects from the shale boom have been shown to stimulate investment in other sectors of the economy (e.g., manufacturing and petrochemicals industry), at the same time ensuring geostrategic positioning in the global energy landscape (Barteau and Kota, 2014). The US shale boom has redrawn the geopolitical energy map, also strengthening its position as a global energy player (Manning, 2014). The EIA energy outlook projected that by 2040, US domestic natural gas consumption will reach 32.2 trillion cubic feet (tcf) with export growth reaching 5.7 tcf (These are pre-Covid projections) (cited in Conti et al., 2016). The shale boom enabled the US to reverse its 2005 trade deficit of $9.4 billion (in the petrochemical industry) to a surplus of $3.4 billion in 2013 (Scott, 2013; Barteau and Kota, 2014; Inman, 2014).

In terms of the multiplying/ ripple effect of job creation, studies suggest that every job created directly from shale gas development resulted in three indirect jobs. The multiplier impact makes shale gas development attractive to many countries burdened by slow economic and job growth (Wang et al., 2014). Wang et al. (2014) demonstrated that the shale industry contributed

US$76.9 billion to the US economy in 2010 and a projected US$231.1 billion in 2025. It is projected that capital investment in the US for shale gas development would have increased to $350 billion, driving growth in employment to 3.5 million by 2035 (Aguilera and Radetzki, 2014). Based on the shale boom, domestic natural gas price in the US reached a 10-year low in 2012 at US$2 per British thermal unit (BTU), (Hasset and Mathur, 2013; Wang et al., 2014), offering more opportunities to monetize LNG exports to European markets (Medlock et al., 2014). The fiscal effects of shale gas activities reported in terms of corporate tax, income tax and royalty payments in 2012 alone were $62 billion (Aguilera and Radetzki, 2014).

4.11 Key Potential Impacts

Several studies highlight that shale gas development may impact the local job market; crowd out non resource aspect of the local economy, disrupt the distribution of revenue, alter the level of poverty, and diminish educational accomplishment (Colborn et al., 2011; Paredes et al., 2015; Marchand & Weber, 2018). Existing empirical studies have reached mixed outcomes about the economic impact of shale gas development on different aspect of the economy (Brown, 2014; Marchand, 2015). It is unclear whether shale gas development is likely to adversely affect or reduce existing local inequities (Econometrix, 2012; Wait and Rossouw, 2019). Study by Van Zyl et al. (2016) argued that a" Big Gas" scenario in the Karoo Basin will spur GDP growth between 8 % to 16 %. Other studies have highlighted that the impact on income and job creation is overstated based on optimistic projections and static predictive models (Andrews and McCarthy, 2014; Richter, 2015). Studies have noted that semi-skilled and highly specialized jobs created by shale gas development are likely to be taken by skilled and experienced migrant workers (Van Zyl et al., 2016). Local content participation could be visible in the lower cadet of jobs and as the field development matures into full production. The Big Gas scenario is projected to create approximately 2,275 onsite and 300 indirect jobs in the logistics sector, growth in low skilled positions between 15 % to 35 % (390 to 900), hospitality, tourism, purchasing and training (Econometrix, 2012; Manning, 2014; Van Zyl et al., 2016; Wait and Rossouw, 2019). Mayfield et al. (2019) found a positive multiplier effect on job creation associated with shale gas development.

Studies have highlighted the potential of natural resource to 'crowd out' the local economy further disrupting the local socioeconomic landscape (Allcott and Keniston, 2018). Van Zyl et al. (2016) suggests that factors responsible for boom-bust experiences associated with natural resource extraction could impose a significant financial stress on infrastructural development resulting in the budget deficit in the Big Gas scenario. Impact on property value is likely to change in response to influx of migrant and population growth.

4.12 Conclusion

Fossil fuels is likely going to continue to play a critical role in the energy mix in the global energy utilization. However, the need to reduce global greenhouse gas emissions is facilitating the shift from less polluting to cleaner form of energy in particular methane and renewable energies. Natural gas is posed as ‘’a bridge fuel’’ to a decarbonised future, however, the high variability and uncertainties in shale gas wells makes shale gas development risky. Large volume of wells and efficient recovery rates are required to make a shale field economically viable.

As the momentum for energy transition increases in South Africa, a need to urgently develop the measures to quantify the economic impacts and benefits of shale gas development including the required investments and sustainable agenda is imperative. The literature review shows the need to develop a comprehensive understanding of production/ volumetric models of the shale wells based on actual drilling data in order to constraint the resource uncertainties. While the shale wells may produce at different rate and peak at different times, it may require the build-up of capacity in other sectors of the economy (such as manufacturing and petrochemical industries) in order to avoid potential crowd out and potential socioeconomic disruptions (experienced during the bust cycles) that may occur at the end of the life cycle of shale gas development. It is also plausible that the transition via shale gas development may overlap development paths to a green future if investment in renewable energy is carried out simultaneously.

Chapter 5: The Social Impact of Shale Gas Development

5.1 Introduction

The world's natural resources are found within indigenous lands and territories. There is growing recognition that advancing large scale development of natural resources infringes on the rights of indigenous peoples' given that indigenous people groups have deep cultural, economic, and spiritual connections with their lands and natural resources. Therefore, indigenous communities represent an important stakeholder of natural resources development (Domínguez and Luoma, 2020). The local community is likely to support the development of natural resources because of the anticipated economic and ownership benefits. However, communities hosting shale gas development may experience a range of environmental, economic, and social impacts. The extent of the impacts is largely uncertain depending on the scale and pace of the development. Studies have shown areas where shale gas development is active encountered a range of social impacts such as scarcity of affordable housing, impact on the social fabric of the community, impact on social services and increase in domestic crime. However, studies have demonstrated that the development of shale resources can be conducted in a sustainable way where the long-term benefits of shale energy development are aligned with the goals of sustainable development. This study classified the drivers of energy sustainability into three broad categories; environmental, economic, and social recognizing that benefits may fit into one or overlap across multiple categories. Determining a hierarchy of absolute benefits may not be as critical as identifying the level of impact on society.

Beyond categorization, the governance of natural resource extraction runs into the dilemma of finding a generalized outcome across the different ethnic groups or geographical space. Not all aggregate benefits and impact of shale gas development are experienced equitably, therefore goals of sustainability may vary from one geographical area to another and are likely to evolve in the long term. South Africa has unique cultural attitudes and social institutions that will require an approach that recognizes the context of geography and the forces of social interaction within the communities that shapes and reinforces individual attitude towards shale gas development. This study argues that the factors influencing the planning and development of shale gas in South Africa are multiple and emblematic of the socio-cultural environment.

5.2 Analysis of the Social Impact

The prospect of shale gas development has generated a remarkable research output, focusing on the nexus between social impact and benefits of the shale technology (Hudgins, 2013; Kerr et al., 2017; Mayer and Malin, 2019; De Groot et al., 2020). It is critical to consider the economic, social, and environmental scenarios of shale gas development within the host community in order to assess the sustainability of the shale technology, which may offer a comprehensive understanding of the essential dialogue between policymakers and the public. This context makes it possible to identify the social risks of the shale technology and appropriate means to situate the technology in a sustainable manner (Mohtar et al., 2019). Research shows that shale gas development could add a wide range of benefits to the community but may also introduce potential risk to the local environment.

Studies have shown that communities can show apathy to technology by associating the technology to a particular risk (such as influx of migrant work force to the community, increase in crime and social vice) or experiences drawn from different context. Issah and Umejesi (2019) explored the broader impact of coal mining in the Karoo and discovered negative perception towards natural resources exploitation. Given this context, shale gas development in the Karoo may be comparable to experiences observed in the boom-and-bust cycles of coal mining in South Africa. This is critical given that the Karoo has a chronicle of health, social and economic disparities associated with the legacy of mining activities (Walker et al., 2018; Issah and Umejesi, 2019). Several researchers argued that the fragile Karoo is at risk should shale gas development move forward in South Africa, noting a 'crowd out' effect in other sectors of the economy (especially in farming, tourism, and manufacturing activities) (Moyo, 2012). Studies have demonstrated that agriculture and tourism hold significant socioeconomic benefits for the Karoo population compared to shale gas development (Milton & Dean, 2010; Gleason, 2013).

Milton & Dean (2010) and Levi (2013) are of the view that jobs generated from shale gas development are short term and unsustainable in the long term given the familiarities associated with boom-and-bust cycles. Israel et al. (2015) demonstrated the effects of uncompensated cost on property owners as a result of decline and depreciation of property and land values. Studies have highlighted significant costs in upscaling and maintaining social infrastructure as a result of influx of people to the community (Christopherson and Rightor, 2012; Abramzon et al., 2014; Newell and Raimi, 2015; Ingle and Atkinson, 2015). Over time, place-based communities are likely to experience disruptions in the social order of the community due changes in the sociodemographic of the community (Fernando and Cooley, 2016; Junod et al., 2018; Toman et al., 2019).

Stretesky and Grimmer (2020) highlighted a clear relationship between shale gas development and crime and demonstrated that domestic crime is likely to increase in communities hosting shale gas development. Levi (2013) explored the characteristics of social disruption caused by natural gas development as a case of moral injustice, a condition that serves the interest of the government, companies, and their shareholders at the expense of the local community. The extent to which the local community can adapt to disruptions caused by the extractive industry have been highlighted in literature with mixed outcomes (Walton et al., 2013; Prno and Slocombe, 2014; Evensen et al., 2017; Luke and Emmanouil, 2019; Luke and Evensen, 2021). Issah and Umejesi (2019) found features of low resilience to the long-term disruption caused by mining activities in the Karoo. Studies by King et al., 2010; Brasier et al., 2011; Chapman et al., 2015; Atkinson et al., 2016 confirmed evidence of low resilience in rural communities of South Africa from natural resource extraction. However, the extent to which shale gas development will alters the social and cultural fabric of the Karoo community is unknown given that shale gas development is still under moratorium.

5.3 The Development of Boomtown and Social Dislocation

Current studies on the concept of boomtown from shale gas development draws on previous research from oil and coal developments. Many of the projects associated with natural resource extraction are situated in rural communities that are unprepared for large scale natural resource developments and associated impacts. The boomtown scenario is closely correlated with the post-development (negative impacts) of natural resource extraction, originally used in the western region of the United States (Jacquet and Kay, 2014; Komarek, 2018).

The extraction of natural resource has a significant impact on the economic and social fabric of the host community, amplified by cycles of boom-and-bust economic activity. While environmental impact assessment may be undertaken to appraise the level of impact on the community during the planning phase, the long impacts of natural resource extraction on the local community are often neglected during the design and planning of projects (Kinneman, 2011). Almost neglected in the broader literature on boomtown is the implication and way in which boom and bust cycles produce new kinds of social dislocation, economic insecurity, poverty, and inequalities amidst rapid economic development in the local community (Black et al., 2005; Allcott and Keniston, 2014; Kelsey et al., 2016). Sociologists, exploring the impact of natural resource extraction on communities employ the boomtown impact model, also referred to as the social disruption hypothesis. The boomtown impact model predicts that communities grappling with rapid industrialization and population growth as a result of natural resource extraction will experience economic loss and breakdown in the social order of the community (Jacquet & Kay, 2014). The development of natural resources largely occurs in less economically diverse areas that are likely to experience shocks or contraction in all aspect of the local economy during period of industrial downturn (Marchand and Weber, 2018). Social scientists exploring the concept of boomtown effects are challenged in understanding the transition and deteriorating socioeconomic performance in the post-boom period. In all cases, the social-economic concerns, and the poor state of welfare in the Karoo through the legacy of mining activities provide evidence of the boomtown effects (Issah and Umejesi, 2019).

Employment rises sharply in the early phase of the boom to deliver economic opportunities, high paying jobs, and earnings to the local population. Jobs created by natural resource development generates an uneven distribution of wages in the local community which can affect the social order of the community. Influx of migrant work force can cause overcrowding of resources and alter the sense of community prompting hostility between the indigenous people and new entrants into the local community. Evidence of deepening inequality between local resident and migrants including escalating xenophobic reaction and negative perception of immigrants in South Africa suggests grave consequences of boomtown effects (Gordon, 2020; Crush, 2021).

Christopherson (2013) provided evidence to support significant population increase during the boom phase that becomes unsustainable during the bust cycle. Although results and risks to communities are varied during the bust phase depending on the scale of the development, population density and funds for mitigation of economic shocks (Measham et al., 2019). Kelly and Schafft (2021) argued that shale gas development proportionately exposed host communities to the effects of boomtown (Fig. 45). Studies characterized the bust phase by fierce social conflict, high unemployment, increase in social inequality, distribution of uneven cost and benefits, high poverty levels, social-psychological stress, increase in crime, distrust, and disparity in educational achievement. Studies have argued that during the bust phase social conflict/ tension is heightened within the community threatening the social order/ fabric of the community (Christopherson and Rightor, 2012; Cosgrove, 2014; Kelly and Schafft, 2021).

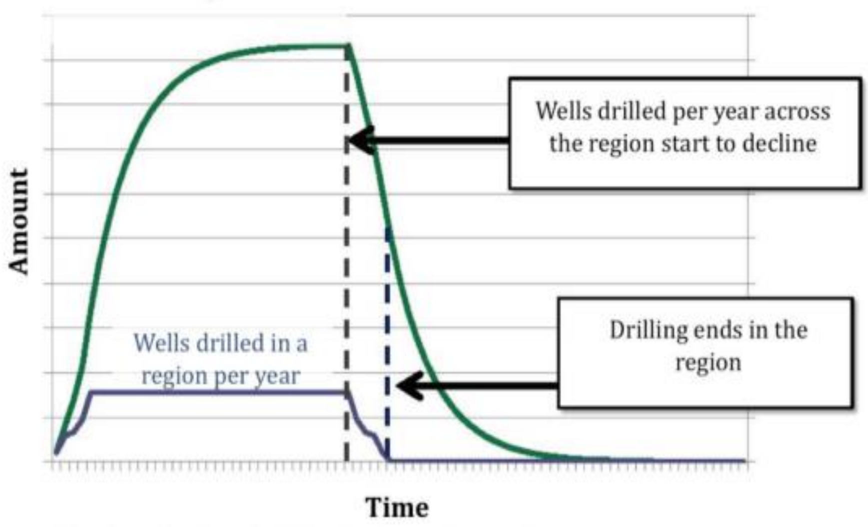

Figure 45: The Case of Energy Booms and Busts.
Source: Christopherson and Rightor (2012).
Notes: The pattern of the Boom-Bust cycle in income, tax revenues and job

Gilmore (1976; 2019) developed the "Problem Triangle" (Fig. 44) to describe the impact and consequence of boomtown effects on communities, the bust period can spiral into negative outcomes as the community convulsed by economic and market disruptions (Murphy et al., 2018). Jacquet and Kay (2014) updated the 'booming' concept to fit contemporary realities and consequences of complex energy systems such as shale energy development. The authors demonstrated that resource-rich countries are likely to experience mini booms and busts compared to the singular classic model of boom-bust proposed by Gilmore. Jacquet and Kay's scenario holds the opportunities for communities to develop resilience from the impacts of resource extraction. The modern reality of the boomtown effect has been examined in communities proximal to the Marcellus Shale site in Pennsylvania. Research indicated that not all communities will experience the effects of boomtown (Brasier et al., 2011; Ruddell, 2011; Ryser & Halseth, 2011; Jacquet and Kay, 2014).

The Gilmore triangle (Fig. 46) depicts a three-part process that defines social disruption in the community. Existing local services and infrastructural development fail to accommodate rapid growth in population during the boom years, results in a poor state of community wellbeing and deteriorating economic performance. The experience of boomtown has a range of consequence on communities such as homelessness from housing-related impacts (housing affordability and availability) as well as the vulnerable who may not reap the benefits of resource extraction. The implication of boomtown requires careful consideration in the Karoo if shale gas development will move forward.

Researchers have critiqued the social disruption model given that the methodologies used to analyse the concept as case-based investigations on small communities (Ennis et al., 2013). Smith et al. (2001) noted that while socioeconomic disruption does occur in communities, however, the impact is contextual and dissipates a few years after the bust. A larger population develop resilience and can absorb significant disruption to the community (Atkinson et al., 2016). Brasier et al. (2011) and Chapman et al. (2015) noted that with the passing of time, social disruption caused by resource development will recalibrate to stabilization, large towns are likely to utilize the revenue/ investment from resource development to diversify quickly and adapt to changes without disruption. King et al. (2010) noted that diversity in the social landscape as a result of migration to the community generates a functional and resilient society.

Gilmore provided a policy management strategy to mitigate the effect of social disruption arising from the impact of resource exploitation:

1. Managing and balancing economic investment
2. Robust planning of resource utilization and conservation
3. Managing human productivity
4. Safeguard the social fabric of the community

Some researchers have challenged the social disruption model on grounds and pointed to the lack of longitudinal data to track pre-boom and post-boom scenarios in the local community that could fail to distinguish small booms/bust within the larger population (Brasier et al., 2011; Chapman et al., 2015). In addition, previous research that utilized qualitative methodology for data collection failed to capture data on crime, population growth and demographic factors (Komarek, 2018).

However, the applicability of the boomtown assumptions and how these might apply to the context of emergent energy economies is contested (Jacquet and kay, 2014). Some researchers argued that lessons from early work on the boomtown effect are instructive for areas where unconventional oil and gas activities are ongoing or being contemplated (Jacquet and kay, 2014; Marcos-Martinez et al., 2019). Given the South African context, much of the experiences of resource exploitation pointed to high levels of socio-economic challenges and disparity in resource distribution (King et al., 2010; Brasier et al., 2011; Chapman et al., 2015; Atkinson et al., 2016). Drawing from this and related natural resource activities in the Karoo, Issah and Umejesi (2019) found that mining activities negatively impacted the social and economic landscape of the Karoo.

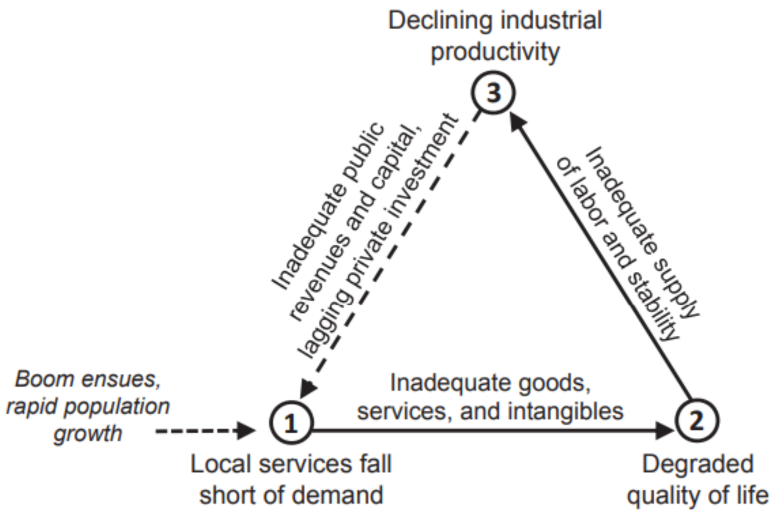

Figure 46: Gilmore Problem Triangle

Source: Muphy et al. (2018).

5.4 Impact of the Resource Curse (The Dutch Disease)

When natural resources are found, the expectation is that their extraction and development will benefit the country. However, developing countries frequently suffer from slow economic growth from the exploitation of natural resources through corruption and weak institutions of resource governance. This concept is referred to as the Resource Curse (Auty and Gelb 2001; Neumayer, 2004; Rosser, 2006; Hitaj et al., 2014). The "rentier effects" is rooted in the economic and political landscape of most Africa countries and defines how these countries manage revenue from resource developments (Dell'Anno, 2020). Studies shows that the Resource Curse is facilitated by rent seeking behaviour. In this context, the Resource Curse refers to the government gaining control of land and other natural resources to secure rents that arise from natural resource extraction. The prevailing institutional weakness coupled with rent seeking behaviour tend to compromise economic productivity in these countries. The earliest work on resource/ institutional curse and implications for national development found that countries with a wealth of natural deposit appeared to grow more slowly than countries without natural resource (Sachs and Warner, 1995; Badeeb et al., 2017). Studies have found that specific channels of resource regression and institutional deficiencies exacerbate unfavourably long-term consequence of natural resource development (Brunnschweiler, 2008; Venables, 2016; Guan et al., 2020). Colgan (2014) found the exception in European countries and notes that the effects of resource dependence to be positive and beneficial to the country. Herb (2005) found limited evidence to support the impact of the resource curse on these economies in terms of rents derived from resource development. Schrank (2004) argued that natural resources have a positive effect on growth performance and by specific socioeconomic indicators outperformed non-mineral economies.

Most studies blamed the reparation of revenue by the extractive companies therefore constraining infrastructural development in the host communities (Humphreys, 2005; Diamond and Mosbacher, 2013; Manzano and Gutiérrez, 2019). Studies by Elbra (2013) and Issah & Umejesi (2019) discovered symptoms of the resource curse in South Africa associated with mining activities, providing evidence that shale gas development meant have the same effect in the country. This is consistent with the findings of Sala-i-Martin and Subramanian (2003) and Ross' (2001a); Torvik (2006) suggesting that wealth from natural resources produces negative impact in Africa countries.

Studies suggested that the effect of the resource curse is too broad enough to have a negative spill over on other sectors of the economy (Wang et al., 2019). The direct impact of capital investment in resource development coupled with technological innovation is correspondingly positive in some emerging economies such as China (Wang et al., 2019). Although there is no direct evidence to link the impact of shale gas development in South Africa to the Resource Curse, given that the shale industry is still at the early phase of planning. However, studies offers both positive and negative impacts of shale gas development (Elbra, 2013; Seekings and Nattrass, 2015; Feyrer et al., 2017). For instance, studies found a significant increase in jobs, wages and an increase in revenue generated from shale gas development (Marchand and Weber, 2015; Feyrer et al., 2017). While studies by Fleming et al. (2015) found negative impact in terms of providing jobs to the local community. The employment created from shale gas development are jobs requiring skilled and experienced personnel in which the host community. lack the capacity to provide. As a result, skilled migrants' workers are likely to outcompete local population in securing the jobs. This is likely the case in the Karoo, given that oil and gas activities is relatively new in the community and level of tertiary education generally low. At best members of the local community will be low-cost labour.

Studies by Farren et al (2013); Muehlenbachs et al. (2015) and Bartik et al. (2019) found that properties local community are likely to increase in value due to high influx of migrant workers therefore leading to the high cost of home ownership or renting. The studies found that the indigenous/ local people are unable to acquire properties due to fierce competition with migrant labour. Conversely, Gopalakrishnan and Klaiber (2014) found a significant drop in the property value in shale gas communities given the environmental concerns of living in areas where shale gas development is active.

5.5 Effect of Socio-Technical Transition in South Africa

The adoption of socio-technical transitions to sustainable energy development are challenging experiences in most societies given that sociotechnical transitions are nonlinear, contested, and disruptive processes (Jacque, 2014; Theodori and Podeschi, 2020; Stretesky et al., 2020). Socio-technical transition involves the switch of cluster of technology, markets, policies, practices, infrastructural networks, individual behaviour and cultural (meanings) variables which occur at a gradual and continuous movement of complex structural change. Accordingly, radical technological innovation in a protected space can trigger complex social and technical changes in the society (Geels, 2004; Mohtar et al., 2019; Xu, 2020).

South Africa is transforming its energy landscape by switching from a high to low carbon economy. Coal fired power stations accounts for 90 % of power production in South Africa. The plan is to ramp up the utilization of renewable energy comprising of Solar 71 % and 28 % Wind power by 2050 and decrease the level of carbon intensity by 50 % in the best policy scenario. This plan highlights the importance of the energy transition and sustainable development in South Africa (Hedden, 2015; IEA, 2019; Thopil, 2021). However, curtailing coal power source and expanding the transition using natural gas from shale gas development introduces a paradox in the transition pathway to the energy revolution. Although South Africa has improved in its development of renewable energy, the paradox of shale gas development present notably challenges in the socio-technical transition. The hinderance results from social, political, economic, and technical factors at the micro level. The trade-off in the energy trilemma will identify if shale gas development remains a priority in the transition pathway in limiting coal-based power generation and expanding renewable energy (Mosse, 2004; Edigheji, 2007; Buscher, 2009).

The Integrated Resource Plan 2010–2030 (IRP) sets the conditions of the transition emphasized the reduction of coal-based power and increase of renewable energies. However, the reality is that renewable energy is progressing at a slow pace of development, at the same time, the coal power stations are aging and nearing their retirement and unable to meet the demand of electricity creating a condition of national energy crisis (Hedden, 2015). The under-deployment of renewable energy means more fossil fuel utilization (coal power) and significant increase in greenhouse emissions. The under performance of the coal stations translates to significant economic losses for industries, businesses and undermine investor confidence. Therefore, proper framework that engages the institutional influence, environmental pressures, and social niche (structural relationship in society) provides an opportunity to accelerate the transition process (Geels and Schot, 2007; Lawhon and Murphy, 2012).

5.6 The Complexities of the Energy Transition

The evolution of societies is closely linked with the interaction between people and energy development. The relationship has evolved from traditional form of fossil fuel energy to modern sources of fuels driven by concrete solutions to improve energy efficiency and sustainability values (Grubb et al., 2008; Essex and de Groot, 2019). The production and distribution of electricity in a sustainable way is the heart of the energy transition, delivered through connected infrastructures which represent a modernist ideal of society. Countries in the global south are making progress towards this ideal by developing sustainable energy across cities and towns. The result in developing economies have been found to be unequitable, appropriation, disruptive to place identity and at variance to the values of local people (Jaglin, 2014; Monstadt and Schramm, 2017).

The pace at which the transition is progressing is changing given the urgency to confront climate change and the need to switch from unsustainable energy sources (Grubbler, 2012; Essex and de Groot, 2019). Sustainable energy systems have become intertwined with many challenging agendas which is requiring a tradeoff between social, economic, and environmental values. The ability of modern energy systems to generate economic growth in an equitable manner, and at the same time tackle environmental challenges (Patel, 2006). Cock's (2004) highlighted the need to incorporate both environmental and social justice in the transition agenda, to address the equitable representation and supply of energy systems to all social groups. This is relevant in complex societies like South Africa ingrained with the legacies of colonial rule, apartheid, and influences of racial disparities. The historical context of energy distribution in South Africa is relevant to the way energy policy is formulated and framed. The legacy of apartheid informs the need to adopt energy policies that provide equitable and sustainable benefits for the population and policies that addresses the social gaps (Mohlakoana, 2014).

The equity implications and cost impact of the energy transition on indigenous communities are rarely acknowledged in the transition debates (Carley and Konisky, 2020; Colvin, 2020). The question of how the transition is situated in the sociocultural context of indigenous communities, who are involved in determining the equity and the interaction that need to happen between policymakers/ governments and indigenous people. Pelletier et al (2019) demonstrated how legacy and historic actions can be used to inform the implementation of a rights-based approach to resource conservation in the indigenous landscape. Similar studies have been undertaken in South Africa highlighting the effects on lands and natural resources (Issah and Umejesi, 2019). Southalan et al. (2011) noted that disputes/ conflict with indigenous communities' challenges conservation systems. The land on which indigenous people live defines their culture and identity, therefore disruption in their natural environment can have significant impacts on the lives of the people and policy implications on energy development. Sustainability in this context means the development of indigenous resources and the processes that integrate the values and interests of the people (Triggs, 2002; Tauli-Corpuz, 2010).

The need to mitigate climate change and provide access to affordable and clean energy set the imperative to transit to a low carbon system. McCauley et al. (2019) showed that the transition must address the issue of energy injustice to ensure that energy and environmental policies assure equitable and fair consideration. An equitable energy justice framework hinged on a holistic approach to assessing the relative merits of resource planning, development, production, distribution, and utilization (Mundaca and Markandya, 2016; McCauley et al., 2019). Broto et al. (2018) argued that energy justice in the Africa context should disregard postcolonial legacy and western traditions to sustain a long-term transition that embraces the traditional values of the local community. In a similar study, Sareen and Haarstad (2018) outlined a theoretical framework that combines elements of energy justice and socio-technical elements in sustainable transitions. McCauley et al. (2019) demonstrated that policy-related processes and changes in institutional structures that address the local context are required if energy transition is to occur quickly in South Africa. The application of energy justice offers a vital perspective that underpins shale gas development in the Karoo, focusing on the community as a critical actor in resource development.

5.7 The Contested Landscape of Energy Development

Shale gas development has radically transformed the energy landscape spurring an outpouring of social science research in exploring social acceptance of shale gas development and how the shale technology can be replicated outside North America (Bugden et al., 2017; Howell et al., 2019; Walsh et al., 2020). Emerging fields in social science and energy research are shaping the discourse of shale gas development. More broadly, social scientists and energy researchers are constructing research methodologies that engage community participation and representation in the development of emerging energy including the effect on culture and the community (Stilgoe et al., 2014; Chilvers and Kearnes, 2015). Over the last decades, fields of research have emerged to fill the gap in public perception by identifying the obstacles to the social acceptance of shale gas development.

The deployment of new/ controversial energy systems may become publicly resisted and contested on the ground that the technology imposes uncertainties, high risks, and negative consequence on the environment. The anxiety may become intensified when the public perceives that the technology may negatively impact the social values of the community (Manders-Huits, 2011; Roeser, 2011; Pesch, 2015; Dignum et al., 2016). In addition, studies show that public acceptance is driven by individual worldview and belief (Lachapelle et al., 2014). Juma (2016) described technological innovation as a social process -the author noted that technology is not the issue, but the way society is constructed and ingrained social values. Juma noted that individuals tend to favor technological innovation if it offers the opportunity for inclusion and aligns with individual values.

Dignum et al. (2016) highlighted that technological artefact is not neutral but provide value to society- (such value may be undesirable). In order to achieve sustainability, Van Gorp and Van de Poel (2006) noted that an acceptable tradeoff of values may be required to improve the social acceptance of shale gas development. It is argued that the three critical factors in considering technological adoption are societal values, the design of the technology, the process of deployment and the institution or geographic space where the technology is deployed (Wüstenhagen et al., 2007; Correljé et al., 2015). Institutions or geographical space are shaped/ constrained by economic, social (traditions, religions, customs) and political factors and tend to structure the way the technology is designed and the context of stakeholder behaviour and the environment in which social contestation occurs (Dignum et al., 2016).

Public perception has significant implications for policy decision development. The benefits of shale gas development are often used to gain public support in siting discourses, but concerns remain of what constitute risks and acceptable impact. Research has shown that the different discourses of shale gas development ranges from environmental, energy security, economic and social factors and these have varying effects on how people make sense of the shale technology (Boudet et al., 2014; Howell et al., 2019). Issah and Umejesi (2019) highlighted that the legacy and impacts from uranium mining and other industrial development in the Karoo influence public perceptions to new forms of energy development. However, studies have shown negative consequences from the mining industry and the effect on the community/ social cohesion including presence of socio-economic disparities in the community (Esterhuyse et al., 2018; Schreiner et al., 2018; Issah and Umejesi, 2019). Supporters of shale gas development highlights economic benefits such as job creation (Brasier et al., 2011; Howell et al., 2019). Studies have demonstrated mixed public responses concerning the shale technology in the Karoo (Chapman et al., 2016; Walt et al., 2018; Willems et al., 2016).

5.8 Evolution of Anti-Fracking Mobilisation

Growing opposition to shale gas development is commonly organized as grassroots mobilisation involving individuals and community-based response (Vasi et al., 2015; Dokshin, 2016). Anti-fracking groups are emerging as key stakeholders in shaping the narrative and discourses regarding the impact of the shale technology. The anti-fracking movement is extending outside North America into new geographies such as South Africa and places where shale gas is contemplated (Bottom, 2020). The anti-fracking movement is also evolving in response to the existential threat of climate change and the wider transition discourse (Bob, 2018; Mihaylov, 2018; Sher and Wu, 2018), drawing awareness and attention to the broader impacts of the shale industry. The success of the fracking groups underscores their ability to lobby relentlessly and actively campaigned against shale gas development which has resulted in government instituting bans or moratorium on shale gas development.

5.9 The Anti-Fracking Movement in the Karoo

Over the last decade anti-fracking activism has been evolving as a local and cross-national/ international social movement (Bob, 2018; Mihaylov, 2018). Public attitude towards the shale gas development continues to play a critical role in shaping the transition debate in South Africa. Through sustained protest and civil action, anti-fracking organizations are raising public awareness of the impacts that could arise from implementing the shale technology. Groups such as the Wildlife and Environment Society of SA, Treasure Karoo Action Group, Centre for Environmental Rights, Western Cape Wildlife and Environment Society, Southern Cape Land Committee, Agri-SA and Earthlife Africa have emerged as local opposition to shale gas development continued to challenge government policy and position of developing the Karoo shales (Ncube, 2017; Academy of Science of South Africa, 2019). Localized resistance is also focused on the broader social and economic impacts on the community.

Local activism to shale gas development reflects the contested way the shale technology is resisted (Andreasson, 2018; Bob, 2018;). The anti-fracking coalition is socially constructed at the grassroots/ community level and galvanized through various online platforms such as social media, townhalls, radical approach through blockage to sites and civil litigations (McCright and Dunlap, 2000; Jones et al., 2014; Hopke, 2015). Studies have highlighted engagement with anti-fracking bodies in the following as key stakeholders in the transition discourse:

- Action towards greater disclosure and transparency need to be acknowledged as a legitimate step in developing the shale industry in the Karoo (Baka et al., 2020).
- The need to create an opportunity for social and political engagement that covers a broad array of stakeholders and active community players in the planning and deployment of the shale industry (Whitton et al., 2017).
- Scientific assessment of the wider implications of the impacts on water, health, and even distribution of benefits and cost (Andreasson, 2018).
- Policy design and corporate social responsibility that delivers long-term investment and economic growth in the Karoo (Solarin et al., 2020).

5.10 Predictors of Social Acceptance

Social acceptance is defined as the degree to which energy development is actively supported, opposed, or passively tolerated by the relevant social actors (Wolsink, 2018). Scholars advocated that the social license to operate must be added as a construct that gives legitimacy to the community as a major stakeholder group. The concept of social license to operate has been widely used as a prerequisite in decision making in environmental and energy policy development (Demuijnck and Fasterling, 2016; Gehman et al., 2017). Decisions regarding the development of natural resources have the potential to impact the social wellbeing of the community (Gross, 2007) therefore, procedural, and equitable (social, economic, and environmental) justice is acknowledged as central to the social acceptance of energy development particularly when such outcomes are perceived to be disruptive and potential threat to the community. The contested nature of shale gas development is clearly visible in the

South Africa shale gas debate, therefore stakeholder engagement with affected and interested parties is proposed as a strategy of citizens involvement, communicating, and responding to the challenges of energy policy (Ngcebetsha and Jamela, 2015; Matebesi and Marais, 2018; Beauchampet and Walsh, 2021).

Figures 47 & 48 presents an overview of the chain of sustainable values identified in literature that links to the principles of resource development in South Africa. The framework provides a deeper understanding of the underlying issues of energy development that are essential for institutional dialogue and communicating policy to the policy. Each set of the value demonstrates the impact of the development and use of shale energy. Taken together, the value hierarchy presents a clear image of the relationship, longer term implications, behaviour, and trade-offs among the different aspect of the elements (IAEA, 2005; Dignum et al., 2016). Firstly, substantive values of the natural resource and the potential impact of the development extend into three areas: security of supply, sustainability, and affordability/ accessibility of the natural resource (Fig. 47). These values also refer to the mitigation of emissions, transition pathway and commitment to global environmental protocols. Secondly, procedural values that relate to policymaking, regulations/ governance of the exploitation of the natural resource. The later concerns also cover the limitations of the legislative system, social representation to the decision-making process, transparency, trust, and distributive justice – such as the unfair distribution of benefits and risks among the social groups in the Karoo (Fig. 48).

Figure removed for copyright reasons

Figure 47: Substantive values and themes in South Africa shale gas discourse.
Source: Modified from Dignum et al. (2016).

Figure removed for copyright reasons

Figure 48: Procedural Values and Themes in South Africa Shale Gas Discourse.

Source: Modified from Dignum et al. (2016).

Changes in the value over time can be used to gauge progress towards sustainable shale gas development.

5.11 Relating Risk Perception to Behavior

The perception of risk is an important determinant utilized to explore the underlying factors influencing the behaviour of people concerning shale gas development. The success of energy development is contingent on the individual/ community perception of risk (Urban and Scasny, 2007; Brasier et al., 2013; Boudet et al., 2014; Clarke et al., 2015; Whitmarsh et al., 2015; Willits et al., 2016). Statistically, risk indicates the likelihood of an untoward or undesirable incident, often expressed in terms of potential threat or harm. Accordingly, it seems reasonable that individuals need to be aware or informed about the risks of shale gas development. How people interpret and evaluate risk (risk perception) is essential in decision making and basis for risk intervention among the target population. Risk perception may deviate from an objective assessment of reality when the individual or public fails to receive the correct information about the situation and are likely to make suboptimal decision. Studies have demonstrated that an individual's perception of risk may be influenced by personal traits or affiliation to a social group. Social groups are differentiated by socio-cultural parameters and sociodemographic variables such age and gender (Michalsen, 2003; Lees, 2012). Therefore, different social groups may have a particular stance to a specific issue related to the shale technology such as strong support or opposed to shale gas development. The influence of social factors on risk perception is a subject of a large body of study that has highlighted how the behaviour of individuals are influenced by the opinion and judgement of the community, awareness of cultural/ social norms and interaction within the community (Klucharev et al., 2009; Zaki et al., 2011; Knoll et al., 2015). This socially driven influence in risk perception depends on the pursuit of social conformity by the individual.

Thomas et al. (2017) argued that when individuals were presented by a range of risks and benefits concerning shale gas development in the UK and the US, participants expressed similar response of risks about the shale technology based on cultural context and place-based experiences. The study demonstrated that public perception of risks and benefits of shale gas development goes further than those included in the formal assessment criteria. The local context and factors ranging from perception about the impact on local community cohesion, institutional distrust and equity provided meaning and broader consideration of shale gas development. Given this outcome, and limitation of technical/ scientific assessment of risk, social scientist advocates the inclusion of public input into risk assessment and all aspect of decision making (infusion of experts and public in a consultative risk assessment) (Eduljee, 2000; Weston, 2004; Williamson and Weyman, 2005; Smillie and Blissett, 2010).

Several studies have highlighted the inherent subjectivity or intuitive elements of experts and non-expert (public) judgement of risks (Kraus et al., 1992; Munns, 2002). In addition, studies have found that experts are deeply divided on opinion regarding the risks of shale gas development. This division places the challenge of risk communication in a dilemma that should be clarified by experts as the public feel vulnerable to the risks posed by shale gas development. Despite the best effort of scientific assessment of risk, it has become apparent that scientific assessment/ method of risks relay on extrapolation and judgement in order to infer and characterize the risks of shale gas development. The direct characterization of risks may be impossible in certain conditions as such the situation can be clarified or improved by inferring it to a similar context. The division in expert opinion as well as the limitations of risk assessment provide the basis for controversies over the risks of shale gas development.

5.12 Public Engagement in Energy Development

Several arguments have been put forward regarding the benefits of public participation as a meaningful input into the decision-making process and governance of natural resource development (Muro and Jeffrey, 2008; Newig and Fritsch, 2009). Public participation provides the opportunity for communication between regulatory agencies and the public, a means by which accurate information can be disseminated to the public in a timely manner (Bird, 2009). In addition, public participation provides the platform to identify, understand and incorporate the interest or expectation of the public into policy making, planning and overall development of the natural resource and also improve the institutional credibility in the local community. While there are several benefits associated with public participation in planning and implementation of policy making, public participation carries some disadvantages (O'rourke and Macey, 2003; Aitken, 2010; Rod, 2011). The process can be expensive, time consuming and may result in institutional distrust and negative perception if public participation is executed poorly (Ferguson-Martin and Hill, 2011). Studies have shown that effective public participation could enhance the social capital and flow of economic benefits (Beierle, 1999; Coleby et al., 2009). Loring (2007) found a positive correlation between effective public participation and increased level of public acceptance of natural resource development.

Given the historical context of apartheid in South Africa, social representation on emerging issues like energy development is complex and influenced by culture, politics, history, and economics ((Brasier et al., 2011; Atkinson et al., 2016; Chapman et al., 2016; Issah and Umejesi, 2019). These factors inform the orientation of public perception and engagement processes in issues related to urban reformation, environment, and socio-economic development (Hamann, 2003). Further, Hamann (2003) added that the complex history of South Africa underpins the laws and policies governing the environment and resource governance thus creating what is referred to as "racially charged and political based institutions". Systemic racism resides in the law, policies, procedures, operations and culture of public or private institutions – reinforcing individual or group prejudices (Ballard et al., 2005; Williams, 2006; Issah and Umejesi, 2019).

Khan (2002) demonstrated that an examination of public perceptions from the different racial constituents is central to understanding the framing of attitudes and policy formation related to shale gas development. Research has demonstrated that the principles of representative (inclusive) participation policymaking are critical to the success of any development planning (Cornwall, 2017). In addition, some factors (such as poor education, high rate of poverty and unemployment) have been recorded in marginalized communities that hinder public participation shifting the focus of the community from issues of national relevance to survival ventures (Khan, 2002).

Bowman (2011) supports this view and notes how cultural diversity and heterogeneity shapes the discourse of energy -South Africa as 'two nations (quote by Thambo Mbeki cited in Hamann, 2003) equates the socio-economic and political disparity of the ethnic groups as racially charged in issues related to natural resources and the environment. Furthermore, Cock and Fig (2001) notes that socio-economic inequality, culture, place, and ethnic characteristics inform the way people are represented and participate in energy matters.

5.13 Conclusion

The development of shale gas resources contributes to the sustainability of communities by providing the population with a range of economic and social benefits. The former has been the focus of numerous studies directed on the impact on economic growth, creation of substantial jobs and stimulating the local business environment. However, the wider social impact and benefits on indigenous communities have not received consistent and comparable attention.

The review of the literature shows that sharing ownership of the energy development with the local community including equitable participation can improve the energy transition. There is a need to align the impetus of energy policy with the buy-in of the local community with a focus on situating energy development within the socio-cultural context of community groups (especially in a heterogeneous society like the Karoo). Policies to sustain these objectives should be flexible and adaptable to mitigate social disruptions in order to maximize the benefits and reduce the negative impacts of shale gas development in the Karoo.

Although the scale of actual benefits and impacts/ risks of shale gas development in the Karoo are uncertain. The potential social benefits include local jobs created boost to economic growth and where applicable spill over in other aspects of the local economy in terms of local empowerment and greater/ positive sense of the community. The potential impacts range broadly and include the rising cost of properties, migration into the Karoo/ population growth leading to change in the sociodemographic landscape of the Karoo, sense of NIMBYism, potential crowd out of the local economy and effects of the boomtown. Notwithstanding, substituting coal power as the primary energy system, to natural gas will ensure the facilitation of the transition pathway to a sustainable green future. The review of the literature suggests the value of modifying energy policymaking concerning shale gas development that builds upon social representation and indigenous institutions.

Chapter 6: Research Methodology

6.1 Introduction

This chapter discusses the research methods and strategies for data collection which enable the analysis of the data to answer the research questions. The chapter starts with an overview of the research paradigm as a fundamental construct that underpins the research design, sampling of the population and choice of methodology. Considerations regarding the ethics, research quality assurance procedures and limitations are also presented. The mixed method approach was used to explore the underlying factors responsible for shaping the perception and experiences of the participants about shale gas development. The choice of methodology was useful in answering the research questions to explore expert and public perception of shale gas development.

The deployment of hydraulic fracking for shale gas development has raised significant public concerns regarding the associated risks and harms induced by the technology on the environment. The level of risk is intensified by the scale of shale gas development (Israel et al., 2015). The use of technical assessment methodologies alone to characterize the risks induced by shale gas development does not always reveal the perception of the public to risk (non-experts) (Sjöberg, 1999; Slovic, 2000; Sidortsov, 2014; Israel et al., 2015). The divergence of risk perception between experts and the public may reflect a range of issues (Cao et al., 2020), level of knowledge/ awareness of the shale technology (Costa et al., 2017), social factors, value systems, trust, distributive justice (Parkhill et al., 2013; Demski et al. 2015), individual belief (Evensen and Stedman, 2017) that are not captured by scientific risk assessment. Studies have demonstrated that public perception may be a result of direct/ indirect experience of the impacts caused by shale gas development (Israel et al., 2015; Howell, 2018).

The broadening of technological risk to include the assessment of public perception is playing an important role in energy research (Ansell & Torfing, 2016; Klinke and Renn, 2021; Renn, 2021). As discussed, findings have demonstrated that the exclusion of communities in the planning and deployment of energy development present practical challenges to energy development. The relationship between public perception and natural resource development is multifaceted and brings into perspective issues of equity, social trust and the way public values and expectations are represented in policy making (Stern, 2013; Israel et al., 2015).

6.2 Rationale to Gather Data from Expert and Public

This study is based on an in-depth interview of 26 experts in South Africa (policy makers and industry experts) to explore participant's perception and experiences about shale gas development. 261 survey questionnaires were distributed across Beaufort West in the Karoo to examine public perception across the dominant social groups in the Karoo. The interview was used to expand on the findings from the survey. This study contributes to literature by identifying and exploring the factors driving experts (policy makers and industry experts) and public (across the dominant ethnic groups in the Karoo) perception of risk about shale gas development. Expert and public perception is an integral component of risk management. It was important to recognise the diversity of values and opinions that exist within and between the social groups in the Karoo communities. Issues of public concerns and relevant to policy making must be accounted in the decision-making process of shale gas development.

This research improves our knowledge of expert and public perspectives as well as their consensus or disagreement on the potential risks of shale gas development. It was important to include experts in this study given shale gas development is a complex scientific development supported by scientific knowledge and the role expert play in the transition development. It is impossible to understand the uncertainties and benefits of shale gas development as well as the options of energy sources without a good understanding of the shale technology.

6.3 The Social Identity Framework in Energy Development

Social group identity describes an individual identification with, and association within, diverse sociocultural groups. The theory addresses how the opinion or perception of individuals are influenced or shaped by the collective value of the social groups (Turner et al., 1979; Hogg and Reid, 2006; Leaper, 2011; Ohlert and Zepp, 2016). The influence of social identity is relevant in a society where individuals believe that their association to a particular social group is fundamental to their wellbeing and self-worth which helps to maintain their sense of awareness and to a large extent defines the way the individuals define their value and personal interest (Bigler and Liben, 2007; Leaper, 2011).

This study relates the concept of social identify to identify and situate the development of shale gas. In addition, this study suggest that social identity occur in the context of addressing the different issues concerning shale gas development in the Karoo. In particular, the influence of social identity has been found to moderate the behaviour/ perception of individuals in a society or within a group (Baumeister and Vohs, 2007; Neighbors et al., 2013). For example, specific perceptions are more strongly/ closely connected with individuals of a social group. In considering the perception or behaviour of individuals about shale gas development is likely to be more influenced by the prevailing values in their social group. These patterns have been observed across different socioeconomic context (poor, mid and high-income earners) nationalities (Northern America, Europe) and ethnic groups (White, Asian, Black). Empirical evidence suggests that bias thrives and sustained within the groups (Liebkind, 2004). In some studies, bias may be more prominent and distinct than others.

The theory of social identity has been demonstrated to have positive correlations with the group and community cohesion (Carron et al., 2002). This is also particularly significant for social identification and determining in-group bias in energy planning and policymaking effort. Brown et al. (1992) argued that minority groups may be overshadowed in social identification by the prevailing level of collectivism in the society. Social groups may be more relevant for relational activities/ purposes but less valuable for individuals who want to be more autonomous or independent. A strong association between the identification of social groups and specific behaviour would be expected that are characterized by relational/ cultural and collectivist preferences. The concept of individualism (e.g., for migrants who want to assimilate into the prevailing social group) may be challenging in societies that have relatively strong and impermeable social groups/ boundaries (such as religious, cultural, and ethnic values). Empirical support has been found for this link in South Africa (Bornman and Mynhardt, 1991; Cakal et al., 2011; Booysen, 2013).

Wohl et al. (2011) found that people subjected to distinctiveness risk/ harm (in comparison to people living in a controlled environment), registered significant support for policies designed to sustain/ preserve the group's uniqueness and dissociate from the dominant outgroup position. A key construct in creating social unrest in a divisive community like the Karoo is anticipating a sense of relative deprivation by a particular social group either to the current energy policy decision or reference to the context of historical injustice by the dominant social group. The implications of shale gas development on the broader cultural and social groups in the Karoo is likely to challenge the social order of the community.

6.4 Survey of Empirical Studies

Extant studies on experts and public perception about shale gas development is underexplored in South Africa. Research has demonstrated that people can express different perceptions of the same phenomenon. For example, technical experts/ specialist and the public assess technological risk differently (Krupnick and Gordon, 2015; Lis and Stankiewicz, 2017). In broad terms, studies have shown the need to account for the scientific/ technical, social, and cultural processes context that shapes the perception of individuals and ultimately constrain their choices/ preference and behaviour. In broad terms, the argument of the acceptability of shale energy development is rooted in the perception of risk and benefit, ‘’constructing if the potential benefits of shale gas development outweigh the risk” or verse versa. The way in which expert and the public ‘construct the meaning’ of shale gas development (including the risk and benefits) including the adjunction in perception between expert and the public present an opportunity for research of shale gas development in South Africa. The US National Research Council (NRC) advocated a deliberative process in the assessment of technological risks and creating a consensus (between expert and the public) in situations where the technological risks are novel, controversial, and uncertain (Israel et al., 2015).

Empirical studies have shown the sense and the extent to which the shale technology is constructed as a social artefact and a predictor of predictor of perception is highlighted in several studies (see literature review – chapter 5). Studies have shown that community character, place attachment and the equitable distribution of costs and benefits can underlie public responses (Bickerstaff and Walker, 2001; Cantrill and Senecah, 2001; Burke et al., 2009; Evensen, 2015; Evensen and Stedman, 2017). In this context, it is simple to see the interaction of the shale technology with the physical world and how the prevailing social activities shapes the deployment of the technology. Technological artefacts are invented by people and so logically, technology must have a social content. Therefore, the contented issue is exploring ways in which the shale technology can be thought of and positioned as an ongoing social phenomenon (Lawson et al., 2007; Lawson et al., 2017; Hornborg, 2019).

Satterfield (2001) highlighted the significance of spatial/ geographical context as a moderating factor in shaping how people or indigenous communities make sense of technology, this can invoke a collective community attitude and response to the technology -given that communities have shared meanings and values referred to a sense of place or place identity (Boholm & Löfstedt, 2004; Simmons & Walker, 2004). Social scientists use the ‘NIMBY’ (Not In My Back Yard) concept as a place protective action which occurs when new or novel technological development near homes or communities interrupt or threaten pre-existing cultural and social attachment (sense of place) of the community (Devine-Wright, 2009). By studying the concept of 'NIMBY' we can further explore the underlying connections between shale technology and the different human/ social interaction that potentially shapes public attitude towards shale gas development.

Willems et al. (2016) conducted a study exploring public perception regarding the impacts and level of social acceptability of shale gas development in South Africa. The study found 22.6 % of the participants support the development of shale resource in the Karoo, 24.5 % of the people were undecided while 52.9 % were strongly opposed to the shale technology. 52.9 % of the participants believe that shale gas development poses significant health and environmental risk, majority of the participants cited water-related issues as the overriding concern to their opposition of the shale technology. The study also revealed that majority of the people derived their information about shale gas development from the media. Shale gas development is presented as an uncertain technology with a significant negative impact/ risk on the environment and human health. Furthermore, the study revealed a high level of institutional distrust in governance.

6.5 The Scope of the Research

Researchers conducting risk perception studies are concerned about how individuals frame their understanding of perceived risks and how such assessment relates to the representation and qualitative characteristics of risk (heuristic). Pidgeon et al. (2003) identified patterns of risk perception among cultural groups and social affiliation and found the link between technological risk with social processes and consideration. Technological events and the growing knowledge base in perception studies is changing substantially in ways in which communities assess and respond to technological risks (Royal Society, 1992). However, research on public perception and behavioural study of risk is fragmented regarding a comprehensive understanding of the social experiences involved in risk assessment. Literature has continually shown a divide between technical and cultural assessment of risk analysis. Therefore, this study provides an integrative and systematic understanding of the technical and social factors underlying risk perception concerning shale gas development.

This study utilized an approach that integrates the qualitative and quantitative methods to provide a broader context and comprehensive understanding of the study outcomes. There are an increasing tendency and agreement within qualitative research to adopt the concept of realism and relativism to form an objective enquiry of different stakeholders (Hammersley, 2018). The divergent viewpoints present significant benefits and attribute to qualitative research. Maintaining a realist viewpoint ignores the way the researcher construct interpretations of the research findings noting that the research findings are factual and reflects an independent reality. Relativism suggests that nothing is definite, that there are divergent realities with none having precedence over the other reality, all perspective represents the truth about the social phenomena (Andrews, 2012; Hammersley, 2018). This is critical in exploring and interpreting the underlying factors shaping people's behaviour towards complex energy systems (Woods, 2006; Yiridoe, 2014).

6.6 Moderating Factors Influencing Perception - Explored

Figure 49 describes the key drivers shaping individual behaviour about shale gas development. The elements are conceptualized and explored further in chapter 7 using the research instrument developed for this study. Five main factors - social trust, stakeholder engagement, social demographic, socio-cultural and factors were identified as justifying further investigation and predictors regarding public risk perception and attitude towards shale gas development. Hakes and Viscusi (2004) found that minority ethnic groups overestimate technological risk than non-minority groups. Savage (1993) found that Black people are more averse to risk. Siegrist (2000) found a positive correlation between trust and risk perception and also found a direct relationship between cultural beliefs and perception of risks. This study advances a multidisciplinary approach in supporting the research aims and objectives. The impact of these factors on public perception is explored explicitly in this study to provide empirical evidence for the findings. The study explores expert knowledge about the risks and benefits of shale gas and the role knowledge plays in policy making and shaping the behaviour of expert about shale gas development. Policy frames for the qualitative instrument was derived from articles and official documents about South Africa shale gas development.

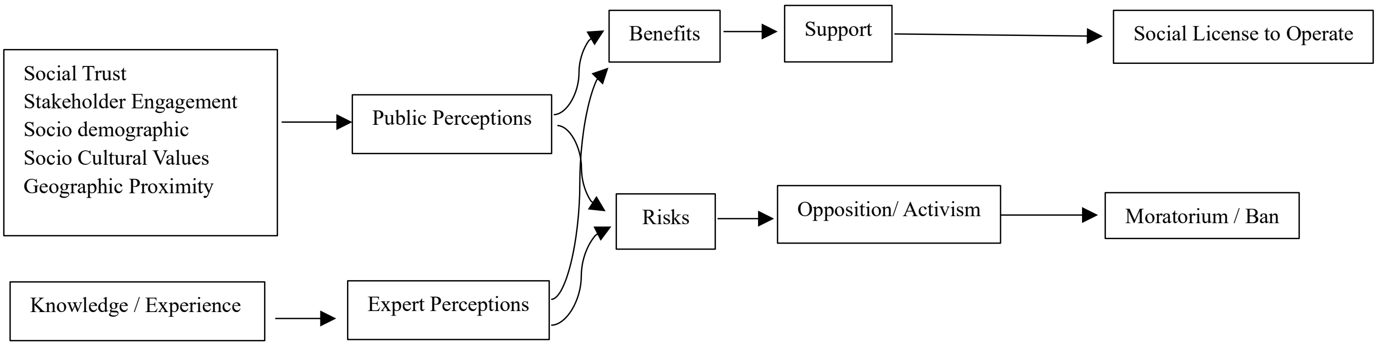

Figure 49: Conceptual Representation of Factors Influencing Perception.

6.6.1 Level of Knowledge

Studies have highlighted that the knowledge gained from extensive experience accompanied by observable facts influences the perception of experts and ultimately shapes the belief (Horn, 2006; Larsson et al., 2019.). The qualitative study examines the expert assessment of risks, benefits, and opinion about shale gas development in South Africa. Shale gas development involves a complex scientific process that requires specialized understanding of the technology and application for energy development which is lacking with the public. Given the assumption of poor public knowledge, governments apply the concept of deficit knowledge to frame policy and communicate to the broader public. The uncertainty and novel aspect of the shale technology, it is not uncommon for experts to express divergent views and understanding regarding the risk and benefit of emerging technology. Studies have demonstrated that public view of shale gas development is driven by poor knowledge and understanding of the shale technology. Extant literature suggests that as expert support of shale gas development correlate with lower risk and higher benefits of the shale technology. This study contributes to the field of perception of shale gas development by analysing and identifying the differences between practitioners involved in shale gas development and non-experts.

6.6.2 Social Trust

Several empirical studies have highlighted the role trust plays in shaping public perception and social acceptability of energy development (Upreti, 2004; Ho et al., 2019). For example, studies found that individuals with a high level of trust in expert are likely to perceive new energy systems to be less risky and more beneficial to society than individuals who demonstrated mistrust of expert (Siegrist, 2000). Conversely, researchers have shown that people who showed a high level of trust in the government ability to effectively manage and govern the technology are inclined to support the development of new energy systems (Siegrist et al., 2005). Furthermore, research has further demonstrated that most people lack adequate knowledge and access to relevant information to make an informed and independent decision about emergent energy technologies (Upreti, 2004). In such cases, the public relies on social trust to reduce the level of complexities associated with risk assessment concerning the technology (Siegrist and Cvetkovich, 2000; Siegrist et al., 2005).

6.6.3 Stakeholder Engagement

The importance of stakeholder engagement in resource development is increasingly acknowledged in literature (Colvin et al., 2020; Cumming et al., 2021). The improvement of public participation and the need to foster effective community communication in order to achieve shared objective has been conceptualised to enhance public perception and impact on policy decision (Baldwin, 2019). Effective stakeholder engagement represents a model for creating a more informed policy outcome and a solid base for conflict resolution. Studies have demonstrated that not all participatory strategies contribute to meaningful opportunities for stakeholders to influence policy decision especially when the engagement does not reflect the values and interest of the stakeholders or social groups (Gregory et al., 2020; Boaventura et al., 2020).

Romenti (2010) demonstrated that the importance of putting stakeholder engagement at the centre of policymaking can increase the legitimacy of the institution to obtain the much-required social license to operate in the community. The norms and rules that specify which stakeholder or social group can participate in the engagement process have been found to shape the perception of the stakeholder on policy issues. Participants have more consistent policy influence when there is a direct relationship in the deliberative process and engagement in the final policy outcomes (Crow et al., 2015). Policymakers can improve the social acceptability of emerging energy systems like shale gas development and the effectiveness of stakeholder participation by integrating interested persons or social groups in the deliberative process and employing norms that make policymaking more comprehensible, transparent, and accessible to all interest groups (Bryson et al. 2013; Baldwin, 2019).

6.6.4 Demographic Factors

Several studies have highlighted the importance of sociodemographic factors in risk perception (Siegrist, 1998; Abrahamse and Steg, 2009; Lee et al., 2015; Boudet 2019; Tutak et al., 2020; Zanocco et al., 2020). Studies found that social demographic variables such as race, age, educational level were significant determinant in risk perception. It is more likely that the strong correlation or relationship between demographic variables and perceived risk observed in other context (e.g., Zanocco et al., 2020) would equally apply to the response of perceived risk regarding shale gas development in the Karoo.

Savage (1993) found that minority people are more averse to risk than non-minority groups. In addition, the study by Adeola (2004) found that racial groups demonstrated divergent environmentalism and risk-avoiding attitude on several factors. Macias (2016) showed non-whites in the US demonstrated a dominant pattern in perceived risks and threats posed by environmental issues. The author found significant statistical measure for race, ethnic groups, and socio-economic status as strong predictors of perceived risks.

Hikes and Viscusi (2004) found that more educated and older people, non-minority social/ ethnic groups tend to appraise risks more precisely and objectively. Similarly, the study found that age and education play a significant driver of risk perception. Savage (1993) demonstrated that low income, less educated women, Blacks, and younger people were more averse to risk/ hazards, and this cannot be explained by poor access to information but by elevated perceived, individual and /experience subjective exposure to risk. Similar evidence was found by Brenot et al. (1998).

6.6.5 Sociocultural Factors

Public risk perceptions are important factors within which policymakers formulate decision regarding energy development. Cultural theorists suggest that sociocultural values, political ideology, and worldviews play a critical role in shaping individual risk perception and public behaviour towards emerging energy development (Bickerstaff, 2004; Leiserowitz, 2006; Boudet et al., 2014). The cultural theory centres on how different social groups and individuals patterned or interpret the world around them. On the other hand, the concept of worldviews refers to the socio-cultural and political disposition of individuals and responses towards complex situations (Leiserowitz, 2006). An individual attitude can be framed by group-oriented social values. Similarly, some studies argued that the important role socially stratified positions play in shaping the rationality of behaviour towards risk, distribution of cost and benefits, energy justice, and view on energy technology (Peters et al., 2004; Leiserowitz, 2006; Thompson, 2018).

Several studies have found a connection between political ideology and public opposition/ support towards shale gas development. The study found that individuals with liberal affiliations (e.g., Democrats) are less supportive of unconventional fossil fuel compared to those with a conservative opinion (e.g., Republicans) (Evensen and Stedman, 2016, Thomas et al., 2017; Zanocco et al (2020). Studies by Davis and Fisk (2014) and Clarke et al. (2016) suggested that the underlying reasons for the polarisation of public views as risk perception, values, and political/ social cues. Similarly, Sjöberg and Wahlberg (2002) found that religious and cultural beliefs play a significant role as a predictor of elevated risk perception.

6.6.6 Geographic Proximity to Fracking Site

Geographic proximity to proposed or existing site of energy development is highlighted in the literature as a predictor of public acceptability of shale gas development, however, some studies have produced contrary perspective. The most common hypothesis about the response to unconventional fossil fuel based on geographic proximity is the not-in-my-backyard (or NIMBY) response. The NIMBY concept suggests that people most proximate to the proposed site for shale gas development are likely to oppose the development of the technology based on the potential impact on the environment and effect on property values (Bell et al., 2005; Schively, 2007; Cotton, 2013; Braun, 2017). However, some scholars have challenged this scholarship and found out that those living close to energy development are more supportive of unconventional energy development (Hoen et al., 2011, Alcorn et al., 2017, Boudet et al., 2018, Firestone and Kirk, 2019) therefore leading to the concept of yes-in-my-backyard (YIMBY) (Smith and Marquez, 2000) and please-in my-backyard (PIMBY) (Brinkman and Hirsh, 2017, Jerolmack and Walker, 2018).

Those who oppose shale gas development in the Karoo are likely to relocate or migrate from the licensed areas should shale gas development occur and those who support the technology may move in for employment and economic opportunities. Underlying public responses and perception lie in the assessment of perceived benefits over costs verse versa during the early phase of resource development (Boudet et al., 2018, Bugden et al., 2016, Bugden and Stedman, 2019, Zanocco et al., 2019). Jerolmack and Walker (2018) argued that public perception of property rights, political ideology, self-reliance, and distrust of liberal belief can drive individuals' attitude towards shale gas development.

6.7 The Rationale of Mixed Method Approach

This study utilized rigorous qualitative and quantitative methodology to collect and analyse the data. The mixed-method approach was useful for this study as it produced a good understanding of the underlying drivers shaping experts and public perception of shale gas development in South Africa. The mixed-method approach was considered relevant for this study because as it offered a broader exploration of the research questions, combining the stories/ personal experiences of the experts from the qualitative study/ interview with statistical analysis generated from the quantitative study (survey data) to give a more complete understanding of the research problems and allowing the researcher to frame the design of the method in a broader study (Holloway & Todres, 2003; Neuman, 2006; Choy, 2014; Creswell, 2014).

The primary strength of the qualitative method allowed the participants to raise nuanced issues pertinent to the current study (Onwuegbuzie & Teddlie, 2003; Yauch and Steudel, 2003). The qualitative data allowed the researcher to ask open ended questions using in-depth interview techniques to infer the emergence of themes or patterns form the study. The quantitative data was gathered using predetermined instruments (Howell, 2018) analysing measurements of attitude/ perception using statistical package for interpretation. The qualitative method was beneficial in describing the perspective of the participants in a limited data set and to appreciate the participants experiences within the context of the study, and to build the study from the participants perspectives. The advantage of the quantitative data method approach was useful in drawing conclusion from a large population (dataset), it was helpful to demonstrate causal relationship between variables/ concepts and explore probable effects of changes in a large population (Creswell, 2014). The mixed method provided weakness reduction and strength enhancement for each of the complementary methods under the same study. It was easy to facilitate the comparisons between groups as well as determine the extent of convergence and disagreement of responses using the mixed method approach (Byrne, 2001; Choy, 2014) (Fig. 50).

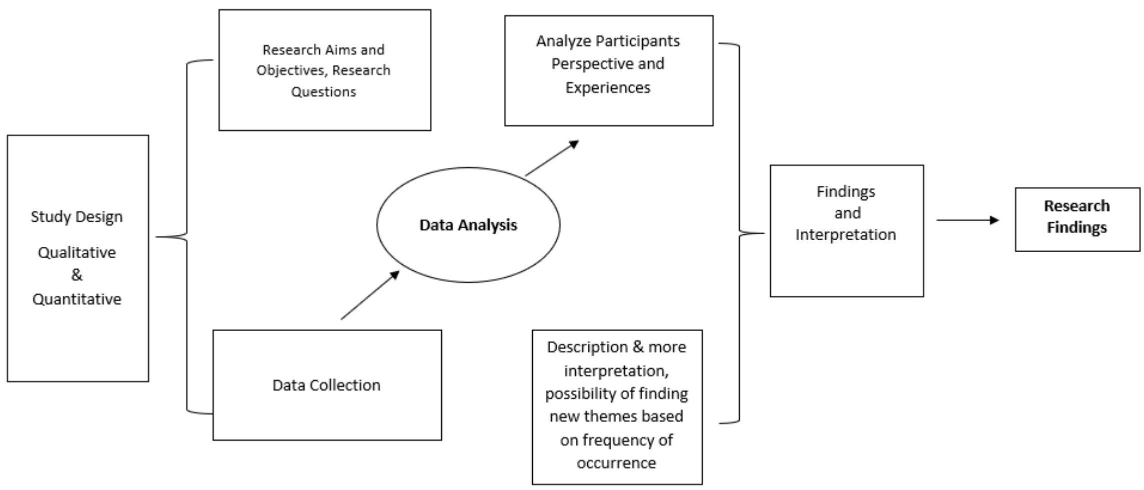

Figure 50: Workflow Mixed Methods Research

6.8 Qualitative Study

6.8.1 Design of the Research Instrument- Qualitative Study

The interview schedule consisted of 9 major items (see Table 16 and appendix 7 for the list of questions) of a structured interview format with a specific number of questions.

Table 16: Research Instrument Development – Interview

Section	Research Instrument Development
1	Support and Opposition
2	Perception of Risks and Benefits
3	Geological and Resource Uncertainty
4	Choice of Energy
5	Karoo Biodiversity (Fauna and Flora)
6	Trust of Resource Governance
7	Source and Access of Information
8	Stakeholder Engagement and Social Representation
9	Change of Perception and Attitude about Shale Gas Development

6.8.2 Selection Criteria and Qualitative Data Collection Technique

The researcher identified professional networks of experts in the oil and gas industry (Geologist, Engineers, and Policy Experts) spread in different parts of South Africa. Some of the participants were identified by exploratory discussions. The participants selected have relevant and variety of experiences in the oil and gas industry, policy-making and broad knowledge of the research setting. A purposive sampling technique was used to identify and select participants for the interview.

Literature rarely suggests the number of participants for qualitative study (Baker and Edwards, 2012; Saunders and Townsend, 2016). However, the literature indicates that the total number of participants for qualitative study should be adequate to satisfy data saturation (Onwuegbuzie and Leech, 2005) highlighting sampling until saturation is achieved as an ideal number to justify qualitative study (Patton, 2015). The recruitment of a broad representation of policymakers and technical experts for the interview enhanced the strengthening of the research instrument and validity of the study.

Twenty-six (η26) interviews/ participants were conducted over three months November 2019 to January 2020 at different locations in South Africa. The interview was conducted face to face and lasted for about 40 minutes until saturation was reached. The interview was conducted in English and audio recorded. The participants were encouraged to express themselves and to provide contextual comments and perspectives if they choose to broaden their responses.

6.8.3 Qualitative Data Analysis – Content and Thematic Analysis

The instrument for the qualitative study was designed to formulate the data collection strategy, organize the data for processing and to make general inferences. A formal set of questions posed to each participant and recorded using a standardized procedure was employed to explore the ideas, knowledge, feelings, opinions/ attitudes of the experts. The qualitative instrument was flexible allowing for the researcher to follow up themes that surfaced from the interview which were enlightening for the aims and objectives of the study. The in-depth interview addressed factors influencing perception and behaviour of experts about shale gas development in South Africa. In addition, the instrument addressed specific impacts, governance, and drivers of behaviour/ perception of risks about the shale technology. The interview was audio recorded and saved in electronic format. The data (η=26 interview transcripts) was transcribed and subjected to thematic content analysis using qualitative software (NVivo v12) (Table 17, Fig. 51). The data was examined in order to identify themes/ recurrent patterns of categories expressing similar meanings. The NVivo software allowed the selection of specific quotations from the audio transcripts which are designated as specific codes representing the theme of each quotation. Several quotations were assigned to specific code allowing the researcher to identify emerging nuances or themes. The codes were examined for causal relationship and category of meaning emerging from the data set. The codes were assigned numerical indicators reflecting the frequency/ number of relationship and density (highlighting the level of importance or significance).

Table 17: Review of Steps used in Thematic and Content Analysis

Phase	Description of the process
Data Familiarisation	Transcribed data read and re-read the data, noted down initial ideas.
Generated initial codes	Coded interesting features of the data in a systematic fashion across the entire data set, collated data relevant to each code.
Searched themes	Collated codes into potential themes, gathered all data relevant to each potential theme.
Reviewed themes	Checked the themes work concerning the coded extracts (Level 1) and the entire data set (Level 2), generated a thematic ‘map’ of the analysis.

Finalised themes	On-going analysis refined the specifics of each theme, and the overall story of the analysis; generated clear definitions and names for each theme.
Findings and outcomes	The final opportunity for analysis. Selected vivid, compelling extract examples, the final analysis of selected extracts, related to the analysis to the research question and literature, produced a scholarly report of the analysis.

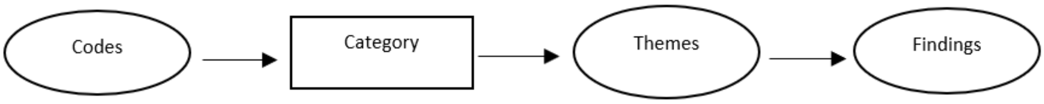

Figure 51: A streamlined Codes-to-Findings for the Qualitative Inquiry.

6.9 Quantitative Study

6.9.1 Design of the Survey Questionnaire

The survey instrument was designed as a self-completion leaflet, contained 55 questions on a 5-point Likert scale- "Strongly agree", "Agree", "Neutral", "Disagree", and "Strongly disagree" option and required approximately 30 minutes to complete (appendix 4). The 5-point Likert scale allowed the researcher to carry out easy quantification, comparison, and summaries of the participants' responses and social reality of the ethnic groups in relation to shale gas development. Participants were requested to indicate their level of agreement or disagreement with each of the questions.

To the level that perception measures capture the social reality of the community, perceptual instruments represent a key element to exploring the impacts of shale gas development. Drawing from a similar methodological and theoretical viewpoint, Greider and Krannich (1985) highlighted on the importance of adding subjective construct comprising of social issues in energy/ perception studies. The authors argued that analysis which focuses exclusively on objective construct may miss salient issues (most important processes and factors) in understanding and interpreting the social reality of the community. Theodori (2009) noted that the process of social reality can be ''soft'' and become ''hard'' in its impact. This study explored public perception regarding the environmental, social, and economic impacts of shale gas development in the Karoo. Given that the geographical area has four distinct ethnic groups, simple random and snowball sampling technique was utilized for the quantitative data study (distribution of the survey questionnaire). 500 survey questionnaires were delivered via one to one between November 2019 to January 2020 to individuals randomly selected at different locations in the Beaufort West area of the Karoo to explore salient local environmental, social, and economic issues associated with shale gas development in the Karoo. A total of η=270 completed questionnaires was returned to the researcher. The length of the survey questionnaire and expected time to complete for each participant was approximately 30 min to 60 min, however, others were willing to take the survey home to complete it. 6 of the questionnaires were partially completed and therefore discarded from the study (Fig. 52).

The fully completed survey was collected and grouped/ labelled under the four ethnic groups (Black, Coloured, India and White). The survey questionnaire returned yielded a 54% response rate was achieved indicating that the instrument used for the study was unbiased, effective, engaging and has sufficient sample disposition (Fig. 52) (Johnson and Owens, 2003).

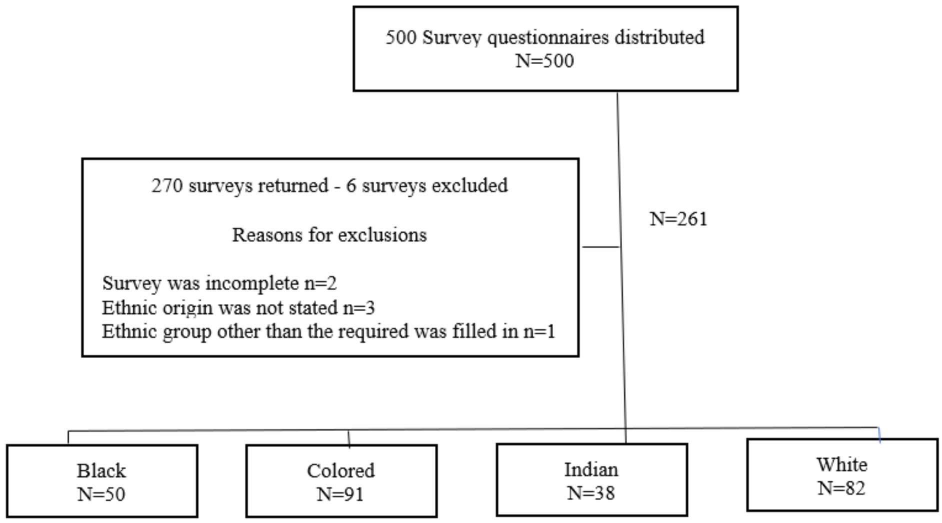

Figure 52: Flow Chart of Participants in the Survey

6.9.2 Survey Format

As discussed above the researcher adopted and modified a series of questions from the work of Howell (2018) designed to measure the participants' perception of shale gas development, including the potential impacts and benefits of the shale technology. A summary of the survey instrument is presented below. Table 18 describes the design of the survey questionnaire into sections (see appendix 4 for survey questionnaire):

- Section 1 described the demographic information of the participant including age, ethnic group, occupation, education, and income status.
- Section 2 provided information about knowledge deficit, environmental risks, economic benefits, and perception regarding the acceptability of shale gas development.
- Section 3 was focused on the participant views on the social impact of shale gas

development.

- Section 4 provided a level of participant awareness of shale gas development, source of information including trust and stakeholder engagement.
- Section 5 focused on resource governance and the implications for social and environmental justice.
- Section 6 focused on the participant understanding of the choice of energy in meeting future demand of South Africa energy needs.

Table 18: Research Instrument Development - Survey

Section	Research Instrument Development
1	Demography and occupation status
2	Perception about risks and benefits
3	Social issues
4	Awareness
5	Governance
6	Karoo-Specific and future of shale gas development

6.9.3 Target Population for the Quantitative Study

The Beaufort West was chosen study area of the quantitative study (Fig. 53). The study site forms part of the Western Cape and straddles the area licensed for shale gas development in the Great Karoo. The study site reflected the differing ethnic groups in the Karoo comprising of Black, Coloured, Indian, and White cultural groups (Table 19) (van Rooyen, 2007). The 2016 South Africa census indicated that the area is approximately 51,080 inhabitants made up of a diverse population (Table 19) (van Rooyen, 2007). Conversely, the Beaufort West constitute an emerging ‘sweet spot’ should shale gas development move forward in South Africa.

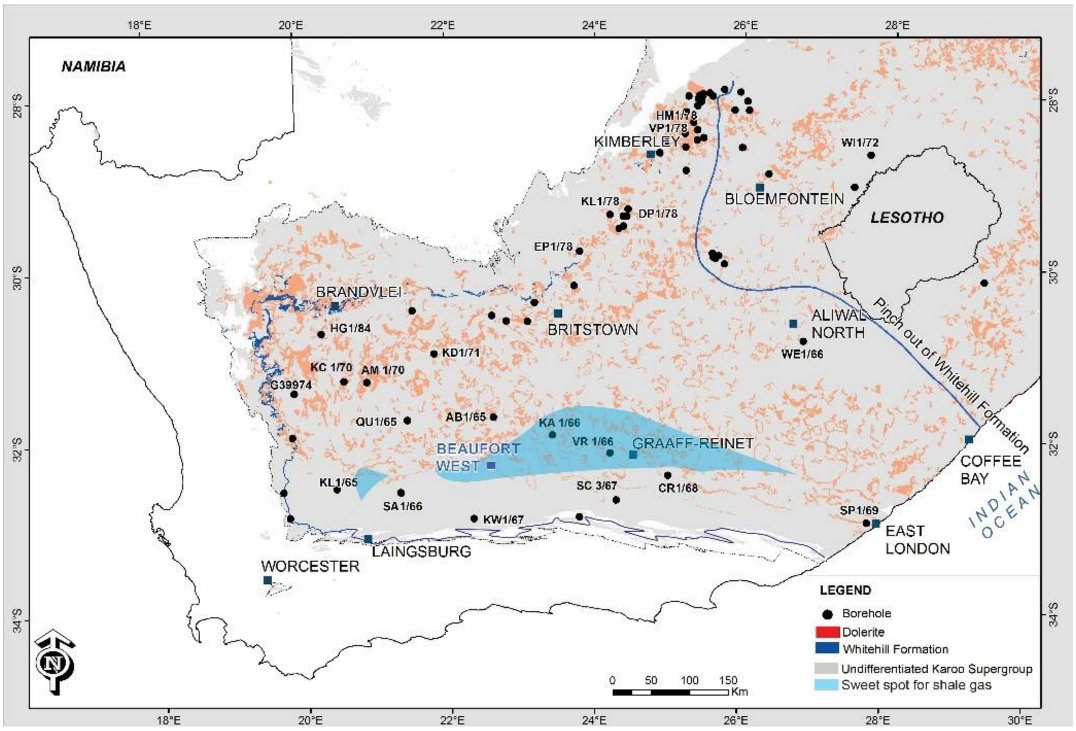

Figure 53: Geological Map of the Study Area.
Source: Pietersen et al. (2021).

Table 19: Demographic information of the District

Table removed for copyright reasons

Source: Adapted from Beaufort West Local Municipality (WC053)
https://municipalities.co.za/demographic/1212/beaufort-west-local-municipality

6.9.4 Quantitative Data Analysis - Kruskal–Wallis (KW) Test

Data entry and analysis was carried out using SPSS version 25. The Kruskal–Wallis is a nonparametric test used for analysing similarities, differences, and the relationship between two or more independent samples (largely ordinal data samples and at least one measurement variable) of equal or different sample size in order to generate sound statistical inferences (Fig. 54). The test functions on limited theoretical assumptions used primarily when the sample data does not satisfy the ANOVA assumptions of normality and the test of differences between the variables and multiple groups. It was also valuable to perform this analysis given the limited sample size collected for the quantitative study (η=261 participants).

The data process involved the calculation of the mean ranks for each of the four ethnic groups (Blacks, Coloured, Indian and Whites) followed by test statistics of H (i.e., the variance of the ranks among the ethnic groups). In a statistical sense, H is approximately the distributed chi-square value. The level of statistical significance expressed in this study is the $p = .05$ (i.e., 5 % chance of finding a difference). The p-value is the probability of finding the observed variable that occurred when a null hypothesis (H_0) holds true or accepted when the p-value is < 0.05. The null hypothesis suggested that statistical observation showed no effect or difference between the set of variables or groups. Conversely, an alternative hypothesis (H_1) is an observation that illustrated some effects or differences ($p > 0.05$) (Goldstein, 2011; Ostertagova et al., 2014; Hazra and Gogtay, 2016). Interpretation of the quantitative study was then based on these results.

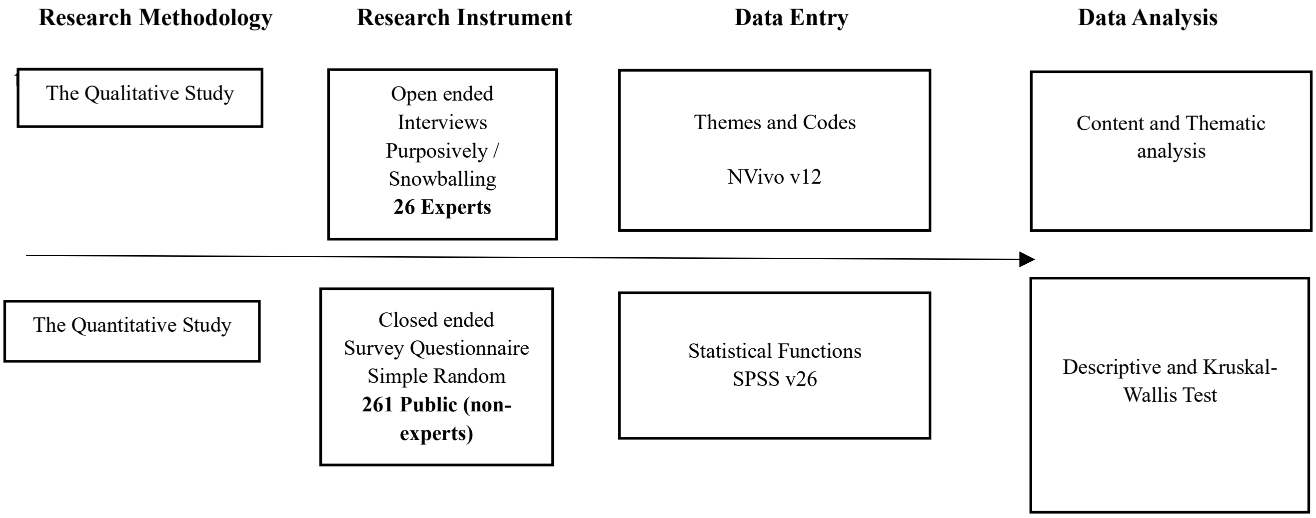

Figure 54: Data Design and Processing

6.10 Ethical Consideration

Blaikie and Priest (2019) posited that good ethical practice requires the informed consent of participants, the voluntary participation of people and ensuring that the participants have the right to withdraw from the study at any time. The practice includes safeguarding the interest, privacy, and confidentiality of the participants according to acceptable standards and protocols of the Ethics committee and Data Protection Policy of Kingston University (appendices 1 and 2). Braun and Clarke (2013) highlighted four ethical principles to be addressed in conducting research: integrity, responsibility, competence, and respect. These principles were upheld throughout the data gathering, analysis and writing phase of this study.

Chapter 7: Findings and Discussions

7.1 Introduction

Factors underlying perception about shale gas development are complex, multidimensional, and interconnected. Understanding the role perception plays in shaping behaviour towards shale gas development have been a subject of significant scholarly and policy research in the last decade (Whitmarsh et al., 2015; Evensen et al., 2017; Thomas et al., 2017; McNally et al., 2018). This scholarly work is positioned as a multidisciplinary study addressing issues related to risk perception and the factors responsible for shaping expert and public perception about shale gas development. Given the potential benefits of the shale technology and significant uncertainty regarding the risks to the environment and human health requires research analysing the underlying factors shaping the perception of experts and the public.

The findings in this study suggest a broad range of perceived positive and negative concerns related to shale gas development. The experts generally support the development of shale gas in the Karoo and demonstrated low risk to human health and the environment while the public showed mixed response with significant opposition demonstrated by the White and Indian ethnic groups compared to the Black and Coloured group who showed significant support of the shale technology.

7.2 Sociodemographic Information - Qualitative Study

The interview instrument contained sociodemographic factors made up of gender, age, professional background, level of professional experience as important descriptive measures about the social dimension of the participant (Table 19) followed by a range of open-ended questions designed to explore participants beliefs, experiences, and attitude about shale gas development in the Karoo (see appendix 3 and 10 for interview questions and codes). The total number of participants interviewed was η26. The participants comprised of 5 Geologists, 5 Reservoir Engineers, 3 Drilling Engineers and 13 Policymakers.

The participants showed a broad range of professional and technical experiences related to oil and gas operations, 46 % of the participants have 5 to 10 years' experience, 27 % of the participants have 11 to 15 years' experience, 15 % of the participants have experienced between 16 to 20 years and finally 12 % of the participants have 21 to 30 years' experience. 69 % of the participants are males while 31% are females, 19 % of the participants have age between 29 to

35 years, 19 % between 36 to 40 years, 36 % of the participants fell between 41 to 50 years old and 26 % of the participant fell in the 51 to 60 years age group. Table 20 shows the sociodemographic background of the experts sampled for the qualitative study. The qualitative sample is divided into two categories: technical experts (e.g., geologist, reservoir engineers and drilling engineers) and policy experts (Table 20).

Table 20: Demographic Characteristics of the Qualitative Sample (η26)

Variable	**Frequency**	**Percentage**
Age /years		
29-35	5	19
36-40	5	19
41-50	9	36
51-60	7	26
Total	26	100
Gender		
Male	18	69
Female	8	31
Total	26	100
Professional Status		
Geologist	5	19
Reservoir Engineer	5	19
Drilling Engineer	3	12
Policymaker	13	50
Total	26	100
Experience Level		
5-10	12	46
11-15	7	27
16-20	4	15
21-30	3	12
Total	26	100

7.3 Qualitative Analysis and Themes

7.3.1 Level of Support and Opposition to Shale Gas Development

81 % of the respondents strongly supported the development of shale gas resource while 19 % opposed shale technology (Table 21). The support of shale gas development is predicated on economic growth through the creation of jobs, support for the local business environment,

mitigate local CO_2 emissions and energy security. The participants also stated that the benefits of shale gas development will generate tax revenue and royalty payments to the local municipality that is essential for infrastructure development. The participants considered that shale gas development could unlock abundant energy resources and access to affordable energy.

Although the experts who supported shale gas development recognised the risks and uncertainties, however, the participants claimed that compliance to best practices and strict regulatory laws will ensure that the environment is safeguarded. On the other hand, the participants who opposed shale gas development highlighted the potential impact on the environment and human health; stated mainly groundwater contamination from spills and leaks of fracking fluids, excessive use of freshwater for hydraulic fracking activities, impact on air quality through the venting of fugitive gases. The participants believed that shale gas development is unsustainable in the South Africa context, given the degree of uncertainties and risks of the shale technology.

Given these concerns, 92 % of the participants supported the current moratorium on shale gas development in the Karoo stating that current evidence is not sufficient to move forward with shale gas development in the Karoo. 8 % (mostly policy experts) disagreed regarding the current moratorium and believed the moratorium is detrimental to the transitional pathway in decarbonizing the energy base. They also stated that significant delay in economic growth should the suspension continuous (Table 21).

According to some of the respondents:

‘’Shale gas development is the immediate energy option to transition to low carbon emission by 2050. It makes sense to support the exploitation of the Karoo shale resources to reduce dependence on coal power, foreign supplies of energy and boost economic growth. Market evidence suggests that the volume and price of shale gas can undercut crude oil reserves”.
Male, Technical Expert, 50 years.

”the current moratorium and impasse on shale gas development in the Karoo should be maintained until there is compelling scientific evidence that addresses public concerns and surrounding impact to the environment and human health”.
Male, Technical Expert, 45 years.

‘’Exploration and development of shale gas in South Africa is urgently

needed to establish South Africa on the map as a gas hub. The abundance of the shale resource in the Karoo is an answer to the issues of an energy shortage, CO_2 emissions and economic growth. The exploitation of the shale resource will reduce dependence on foreign supplies".

Male, Policy Expert, 50 years.

''The national outlook for shale gas development is positive, however, relevant legislation and laws need to be established to improve stakeholder participation and broader community benefit".

Female, Technical Expert, 43 years.

'' Shale gas development will allow South Africa to tackle the shortage of energy in the short term, while the country diversifies the long-term national energy framework to include renewables and bioenergies".

Male, Policy Maker, 43 years.

Table 21: Are you in support of fracking /shale gas development in the Karoo?

Participant Type	Responses of interviewees			
	Total	Support	Neutral	Oppose
Geologist	5	3	-	2
Reservoir Engineer	5	4	-	1
Drilling Engineer	3	2	-	1
Policymaker	13	12	-	1
Total n	26	21	-	5
Percentage (%)	**100**	**81**	**-**	**19**

Table 22: Do you support the current temporary ban on fracking in South Africa?

Participant Type	Responses of interviewees			
	Total	Support	Neutral	Oppose
Geologist	5	5	-	-
Reservoir Engineer	5	4	-	1
Drilling Engineer	3	3	-	-
Policymaker	13	10	-	3
Total n	26	22	-	4
Percentage (%)	**100**	**92**	**-**	**8**

7.3.2 Expert Perception of the Risks and Benefits of Shale Gas Development

When presented with a range of potential risks and benefits associated with shale gas development. 85 % of the experts demonstrated that the benefits of shale gas outweigh the potential risks of developing the resource. On the contrary, 15 % of the participants argued believed that the risks outweigh the benefits (Table 22). In addition to the scientific knowledge and empirical studies, the participants were able to draw a broader understanding of the potential benefits, risks, and community implications of shale gas extraction from their professional background, lessons, and experiences in the US, from contextual understanding of the Karoo geology to frame their perception of the wider impact on the Karoo. The experts showed that emerging shale gas countries like South Africa will benefit from an archive of lessons learnt from the US experience to design adaptive mitigation and regulatory strategies to run the industry in a sustainable manner.

According to some of the respondents:

South Africa has a unique advantage of developing its shale industry from lessons learnt from shale gas development in the US.
Female, Policy Maker, 30 years.

''in addition to the conditions of public acceptance and the geological, the supportive regulatory context, socioeconomic and environmental factors that led to the shale boom in the US are remarkably different from South Africa. To an extent, some of these conditions can be replicated in the Karoo".
Male, Technical Expert, 34 years.

''Despite the uncertainties surrounding the development of shale resource in the Karoo. Shale gas has considerable advantage than coal, it is much cleaner and less polluting than coal, it is also much cheaper to produce than renewable energies and has the potential to boost South Africa's economy, generate jobs and stimulate local businesses".
Female, Policy expert, 45 years.

''There are indications that hydraulic fracking has resulted in water contamination and impacted the quality of the atmosphere from the release of fugitive gases. In some areas, fracking and waste disposals have led to earthquakes activities. I believe the risks outweigh the benefits; we should focus investment on renewable energies".
Female, Technical Expert, 40 years.

''Earthquakes are rare events in South Africa, the likelihood of shale gas or hydraulic fracking activities triggering seismic activities is limited. Geologically, South Africa is located on a relatively rigid plate boundary that makes the likelihood of induced seismicity happening remotely impossible. I believe that seismic monitoring should be carried during and after shale gas operations are conducted so we can monitor the effects on the subsurface and design appropriate mitigation plan".

Male, Technical Expert, 56 years.

''We understand that some of the chemicals used for hydraulic fracking operations are toxic and could potentially contaminate surface water sources. Well integrity failure and gas venting during production operations serve as a pathway for fugitive gas to escape into the atmosphere impacting the local air quality. The use of water for fracking operations is likely to deplete domestic water sources and impact other industrial activities".

Female, Policy Expert, 40 years.

''In most cases, methane contamination of shallow aquifer comes from biogenic sources that are not attributable to shale gas development. An alternative pathway for potential pollution can be reduced by using best practices".

Female, Policy Expert, 45 years.

Table 23: What do you consider potential benefits outweigh the risks of shale gas development?

Participant Type	Responses of interviewees			
	Total	Benefits	Neutral	Risks
Geologist	5	4	-	1
Reservoir Engineer	5	4	-	1
Drilling Engineer	3	2	-	1
Policymaker	13	12	-	1
Total n	26	22	-	4
Percentage (%)	**100**	**85**	**-**	**15**

7.3.3 Strategy of Resource Governance

Estimates of technically recoverable resources, gas-in-place, and future production of shale gas in the Karoo are characterized by a high level of uncertainty (described in chapter 2 of this study). Different resource estimates have been put forward by different bodies. The government precautionary strategy in the planning and developing the Karoo shale resources presents a rationale to gather evidence to reduce the uncertainties, support investment and improve public confidence. The presence of dolerites and complex depositional/ thermal history of the Karoo Basin was described by the experts as gloomy for commercial presence of gas. The experts described that the lack of infrastructural development, poor regulatory framework, and lack of skill resource in South Africa will require significant investment in moving the industry forward making the shale industry uneconomical in the short term. Furthermore, the participants highlighted that the absence of mineral rights to landowners in the US is remarkably different in South Africa. With these, 50% of the participants expressed doubt regarding the potential of the Karoo basin to replicate the US boom stating that the US experience cannot be generalized to the South Africa context. 50 % noted that South Africa can replicate the shale boom given the history of natural resource development in South Africa and leveraging from the lessons learnt from the US shale boom (Table 23). as illustrated in the quotes:

‘’The success of shale gas development in the United States cannot be replicated in South Africa based on conditions that are unique to the US, conditions such as favourable geological features, strong regulatory and institutional framework, established infrastructural and market conditions and advanced technological capabilities. South Africa does not have these conditions to replicate the benefits of shale gas development as America. The Karoo shale resource may only be optimal for domestic use”.
Male, Technical Expert, 56 years.

South Africa can adopt a similar US-led methodology to the regulation of the shale extraction industry, this approach will impose higher regulatory oversight and on operators to comply with safety standards. This position is likely to replicate the US shale boom in South Africa.
Female, Policy Expert, 40 years.

‘’The government has conducted several feasibilities and scientific studies that suggest a favourable economic and energy security outcome of developing the Karoo shale reserves”.
Male, Policy Experts, 41 years.

Table 24: Do you agree that South Africa will have a shale boom?

Participant Type	Responses of interviewees			
	Total	Agree	Neutral	Disagree
Geologist	5	-	-	5
Reservoir Engineer	5	1	-	4
Drilling Engineer	3	-	-	3
Policymaker	13	12	-	1
Total n	26	13	-	13
Percentage (%)	**100**	**50**	**-**	**50**

7.3.4 Choice of Energy Development

The participant agreed that developing the shale resource provides a viable option to mitigate local CO_2 emissions. There was consensus among the experts concerning renewables (wind and solar) as the preferred energy for the future (Table 25). It is in this context that policy experts advocated for an effective and viable path to sustainable energy development contrary to the idea that shale gas will out compete the investment in renewable energies. The experts demonstrated that shale resource is abundant, cheap to produce and less damaging to the environment compared to the current energy base -coal power. The experts claimed that total production of renewable energy - wind and solar energies is currently limited requiring a bridge fuel to maximize the contribution of power generation. When shale gas was compared to the other energy sources, shale gas was preferred after renewable energy as illustrated in the following quotes:

‘’The rationale for shale gas development in South Africa reinforces the need to shift from high carbon sources to a net-zero economy based on slowing down climate change realities. I believe that shale gas is the optimum bridge energy that would lead South Africa to the desired emission target and energy security.”

Female, Policy Expert, 34 years.

We have to reduce our dependence on coal energy. Shale gas is the best option we have in our transition path to renewable energies. The impacts of shale gas development are a result of poor practices. We must ensure best practices and lessons from the US experience are applied ‘’.

Male, Technical Expert, 55 years.

‘’Shale gas allows us to move in the direction of renewables. It also gives

us the incentive to reduce our CO_2 emissions by reducing the use of coal power. The production of energy from a renewable source is insufficient to meet national electricity demand, so we need shale gas as transition energy.” ***Female, Technical Expert, 40 years.***

Table 25: Is shale gas the optimal transition energy to a sustainable future?

Participant Type	Responses of interviewees			
	Total	Pro	Neutral	Anti
Geologist	5	5	-	-
Reservoir Engineer	5	5	-	-
Drilling Engineer	3	3	-	-
Policymaker	13	13	-	-
Total n	26	26	-	-
Percentage (%)	**100**	**100**	**-**	**-**

7.3.5 Potential Impact on the Karoo

All the experts revealed the potential for biodiversity loss can occur at any stage of shale gas development project, from exploration to production of the gas. The experts highlighted the impact shale gas development could cause on the local habitat leading to disruptive changes in wildlife population. The experts argued that aquatic life may be at risk due to water pollution resulting from shale gas activities. In addition, the participants revealed that shale gas development could induce and accelerate land fragmentation and constrain agricultural development. The use and competition of domestic water in a water scarce Karoo for shale gas development was suggested by the experts that water supplies can be abstracted sustainably. Spillage and infiltration of fluids into the subsurface, surface water bodies and land present a channel for impact on the fragile Karoo ecosystem and damage to the natural habitat. In addition, the experts demonstrated that breathing of chemical particles during delivery or at the mixing site has the potential to cause respiratory problems. Pollution triggered by fugitive methane and VOCs into the atmosphere also contribute to health issues. Site and road construction was believed to produce ecological disturbance. Low level seismic activity resulting from activities in the oil, gas and geothermal energy sectors is well known. The level of seismicity means that impacts are generally minimal, though there are circumstances in which the consequences could be more severe (Table 26) as presented in the flowing quotes:

''It is important to develop an appropriate planning and ecological conservation agenda that protects the environment and the local people. That means recognizing the Karoo endangered biodiversity as an important aspect of the environmental and social impact assessment process while showing commitment to protect the sensitive fauna and flora of the Karoo during the planning of shale gas development."

Male, Technical Experts, 34 years.

''The fracking operation requires a large footprint of land. Roads will have to be constructed and large well pads build to accommodate all the equipment. The main risk is on the surface (and not sub-surface) where sensitive fauna and flora might be destroyed during surface construction and possible spills on the land."

Female, Policy Experts, 45 years.

''The broader environmental and landform changes caused by shale gas development can be reversed by reclamation and restoration practices. It is my view that activities of shale gas development will not irreversibly damage the environment as long as the regulatory requirement provides the scope and flexibility for the development of novel and hybrid ecosystem".

Male, Policy Expert, 52 years.

''The value chain of shale gas development could significantly impact water supplies in the Karoo, however, advances in water treatment and recycling technology can be utilized to abstract the water sustainably ''.

Female, Technical Experts, 50 years.

''Although the release of methane gas can arise during production cycles which is harmful to human health. Release of fugitive gas can be managed efficiently through strict rules and laws prohibiting companies from flaring activities and through carbon capture technology, so impact on air quality can be reduced".

Male, Policy Experts, 45 years.

''Hydraulic fracking can induce seismicity, though, these events are not felt at surface because hydraulic fracking occur at greater depths. The risk of large earthquakes by hydraulic fracking activities is significantly low. In addition, incursion of stray gas into the aquifer is insignificant due to competent casing and the great depth of hydraulic fracking activities. Under certain conditions, biogenic gas can infiltrate shallow water wells, this is unlikely in the Karoo ''.

Male, Technical Experts, 55 years.

''The incursion of migrant workforce into the Karoo is likely to distort the socioeconomic landscape of the community, create social tension and competition for resources. The infrastructure may be stretched, crime may increase, and housing may be limited and expensive in the long term. The source of livelihood for the people is also likely to be threatened as young people aspire to get jobs in the shale industry ''.

Female, Policy Experts, 48 years.

''I am concerned that the development of shale gas will increase the level of inflation and cost of living in the Karoo. The shale industry will put pressure on local businesses who are unable to compete with the influx of foreign firms into the Karoo"

Male, Technical Expert, 57 years.

''It is a given that the Karoo community will be under strain resulting from shale gas development. The community will attract an influx of migrant's workforce and foreign businesses re-enforcing government need to establish community resilience and regulation relating to local content during the life cycle of shale gas development to avoid the socio-economic problems associated with natural resource development".

Female, Technical Expert, 50 years.

''We have seen that good policy and economic intervention can ameliorate the effects of post-boom fallout. I believe this is achievable".

Female, Policy Expert, 43 years.

Table 26: What is the impact of shale gas development on the Karoo?

Participant Type	Responses of interviewees			
	Total	High	Neutral	Low
Geologist	5	5	-	-
Reservoir Engineer	5	5	-	-
Drilling Engineer	3	3	-	-
Policymaker	13	13	-	-
Total n	26	26	-	-
Percentage (%)	**100**	**100**	**-**	**-**

7.3.6 Institutional Trust

Institutional trust is critical for the success of a broad range of policies that hinge on behavioural responses from people. Although shale gas development may bring an infusion of economic growth to the Karoo, experts expressed concerns about an array of risks if the industry is not properly governed. The experts agreed that institutional based trust is important in designing policies and developing strategies for sustainable energy development. 38% of the experts stated that a high degree of institutional trust for the central government to regulate practice and oversight of the shale industry while 62 % of the experts exhibited low trust based on past failures of the central government to govern and sustain the development of national resource. 38 % of the participants of shale gas development noted that the required skill and experience to properly govern the shale gas industry is lacking in South Africa. The lack of trust and transparency on the part of the companies to fully disclose the chemicals used to compose hydraulic fracking fluid was high among the experts (Table 27). The experts noted that past failures in resource governance in South Africa has damaged public trust and confidence to develop the shale resources sustainably.

The legacy of failures by government in the extractive industry has compromised the confidence and inclination of people to respond positively to public policies ‘’.

Female, Technical Expert, 50 years.

‘’Public trust is an important factor in shale gas development. I believe that the lack of trust has deteriorated and need to be restored to attract significant investors in shale gas development ‘’.

Male, Technical Expert, 57 years.

‘’I believe that the institutions in the country are built on a high level of fairness, integrity and have been consistent in delivering equitable service. The institutions are accountable, resilient, and strong predictors of public trust ‘’.

Female, Policy Expert, 34 years.

‘’The legitimacy of the institutions is strong and able to enforce compliance and best practices ‘’.

Male, Policy Experts, 41 years.

Table 27: What is your level of institutional trust and governance of shale gas development?

Participant Type	Responses of interviewees			
	Total	Low	Neutral	High
Geologist	5	5	-	-
Reservoir Engineer	5	5	-	-
Drilling Engineer	3	3	-	-
Policymaker	13	3	-	10
Total n	26	16	-	10
Percentage (%)	**100**	**62**	**-**	**38**

7.3.7 Source and Access to Information

The level of support about energy policies and how risk is perceived is influenced by the quality of information. The perception of an individual is impacted by subjective processes, personal experiences and the context of the situation which may be different from reality (Javanmardi et al., 2020). The experts were asked about the sources they use to draw their judgement or shaped their perception about shale gas development. The experts expressed their consensus on the strength of scientific evidence published in a range of academic literature and accredited industry publications such as The Society of Petroleum Engineers (SPE) and The American Association of Petroleum Geologists (AAPG) as credible sources of information concerning shale gas technology (Table 28) as illustrated in the following quotes:

''Although lessons can be drawn from areas where shale gas development is active, the absence of geological and drilling information or data makes it risky to invest in shale gas development in the Karoo".
Male, Technical Expert, 54 years.

''While different sources exist for information concerning shale gas development, however, evidence-driven sources of information and peer-reviewed by scientist and experts are the right source of information".
Female, Policy Expert, 34 years.

''Access to credible information plays a critical role in influencing public attitude and beliefs especially in a situation where the public does not have direct access to regular and updated information from experts for them to make a quality judgment. The impact of social media and other unscientific sources have done more harm than good in sending out information that is not peer-reviewed or substantiated by scientific evidence. The source of

credible information concerning shale gas development is academic journals and professional bodies such as the AAPG and SPE".
Female, Policy Maker, 40 years.

Table 28: What is your source of information of shale gas development?

Participant Type	Responses of interviewees			
	Total	Peer reviewed/ Academic / Industry	Neutral	Other sources
Geologist	5	5	-	-
Reservoir Engineer	5	5	-	-
Drilling Engineer	3	3	-	-
Policymaker	13	13	-	-
Total n	26	26	-	-
Percentage (%)	**100**	**100**	**-**	**-**

7.3.8 Stakeholder Engagement

Effective stakeholder engagement in energy development projects aims at improving knowledge sharing, expanding ownership of the project by the different stakeholder, mitigating social conflicts, and promoting innovation. The value inclusive decision making and building social capital is critical from an ethical perspective and crucial for sustainability assessment. Studies have shown that effective stakeholder engagement provide a forum for social learning, where diverse people share their values, experiences, expectations and build shared objectives and vison (Mathur et al., 2008). Dialogue is critical in broadening awareness and changing perspectives or behaviour.

Given that stakeholder engagement and consultation are still evolving in the early phase of the planning process. The experts recognized the need to develop both adaptative and collaborative engagement strategies that are context-specific, inclusive of experts, individuals in the host community and interested/ affected parties in order to improve multi stakeholder dialogue in decision making. 54 % of the experts acknowledged that current public engagement and consultation strategies does not go far enough in representing the values of stakeholders in policy making about shale gas development. While 46 % of the participants believed that current engagement strategies reflect significant improvement in developing sustainability assessment of shale gas development.

''I believe that public consultation regarding decision making has been largely inadequate and less engaging in representing what the community need in resolving their concerns about their values and interest about shale gas development. The engagement can be improved''.

Male, Technical Expert, 57 years.

''Community engagement is a critical aspect of the decision-making process for shale gas development. As such, policymakers have regular town hall meetings and consultative forums to address community concerns. This has been very effective and engaging''

Female, Policy Maker, 40 years.

''Much need to be done to improve and broaden stakeholder engagement concerning shale gas development in South Africa in order to garnish support and success of the shale project. The level of opposition indicates that current engagement has not been effective to encourage public confidence and assimilate the different values and interest of the different stakeholders ''.

Male, Technical Expert, 54 years.

Table 29: What is your level of satisfaction regarding stakeholder engagement and social representation?

Participant Type	Responses of interviewees			
	Total	Acceptable	Neutral	Disagree
Geologist	5	1	-	4
Reservoir Engineer	5	1	-	4
Drilling Engineer	3	-	-	3
Policymaker	13	10	-	3
Total n	26	12	-	14
Percentage (%)	**100**	**46**	**-**	**54**

7.3.9 Change of Perception and Attitude

It is widely acknowledged that social acceptability poses a significant barrier towards shale gas development especially when public opposition is characterized by mixed messaging and lack of expert consensus regarding the impact of shale technology. Risk perception has been found to trigger a set of complex individual responses associated with the behaviour of people towards shale energy. The variability of perception among experts reflects the multidimensional and complex nature of shale technology.

Participants were asked if they will change their perception regarding shale gas development in the face of new scientific evidence and findings. 100% of the participants indicated that they would change their perception and attitude in the event of persuasive and compelling scientific evidence (Table 30) as illustrated in the following quotes:

' 'I will definitely change my perception about the risks and benefits of shale gas development should sufficient and factual evidence becomes available. I believe that scientific and empirical evidence should always priority and guard policy making regarding shale gas development".
Female, Policy maker, 42 years.

''My understanding of shale gas including the associated risks and benefits informed by scientific evidence. Science and technology are evolving and improving, new evidence will change my perception".
Male, Technical Expert, 51 years.

Table 30: Is your perception or opinion about shale gas development likely to change in future?

Participant Type	Responses of interviewees			
	Total	Yes	Neutral	No
Geologist	5	5	-	-
Reservoir Engineer	5	5	-	-
Drilling Engineer	3	3	-	-
Policymaker	13	13	-	-
Total n	26	26	-	-
Percentage (%)	**100**	**100**	**-**	**-**

7.4 Quantitative Study

The quantitative study involved η261 participants across the Karoo population. The quantitative data were collected using 59 item survey questionnaires based on a 5 Likert-scale modified from a research instrument that has been validated from similar studies. The Kruskal-Wallis (KW) nonparametric statistical test was performed based on ranked mean and median data to compare the overall equality across the groups ethnic (Black, Coloured, Indian, and White) rather than using the raw or original observations. The KW test was used to establish if there are statistically significant differences between the four social groups (Black, Coloured, Indian, and White) of an independent variable on a continuous or ordinal dependent variable. When statistically significant differences were found among the groups or variables, a single post hoc test comparison was executed for multiple comparisons. The data analysis was performed with the SPSS statistical package (version 25). A level of significance of $p<.05$ for comparative measurements was used throughout the analysis. The KW, mean, median and pairwise comparisons output for the four groups is presented in appendices 7, 8 and 9 of this study.

To determine whether any of the differences between the medians are statistically significant, a comparison of the p-value was assessed for the null hypothesis (H_o). Under the null hypothesis, the KW test is distributed asymptotically as chi-square with a k - 1 degree of freedom. It was assumed that the data collection was continuous and randomly drawn from the Karoo population. Table 29 summarizes the sociodemographic of the participants used for the quantitative study. The table indicates the breakdown of the participants according to their social-cultural variables. The sociodemographic profile describes the gender profile, marital status, occupation, annual income, and educational background of the 261 participants.

7.5 Descriptive Statistics and Sociodemographic Profile

In terms of ethnicity, the number of people who participated in the quantitative study is presented as follows: Blacks 50 (19 %), Coloured 91 (35 %), Indian 38 (15 %), and White 82 (31 %). The demographic profile showed participants between the ages of 41 to 50 years old as significantly represented (28 %) in the study, followed by participants between 18 to 30 years old (25 %), between 31 to 40 years old (23 %), between 51 to 60 years old (14 %) and lastly people from 61 years and above were lastly represented (10 %) (Table 29).

The demographic profile showed a significant difference in the level of education between the groups; the White group showed the highest form of educational attainment (58 %) (Graduate and postgraduate degree), compared to the other ethnic groups who showed significantly lower educational level (Diploma, Matric and below matric levels). In terms of occupation, 31% of the participants claimed to be farmers compared to 23% entrepreneurs, 17% government employees, 15% retail/ tourism industry and 12% engaged as construction workers (Table 31).

Table 31: Sociodemographic Characteristics of the Quantitative Study

	Ethnic Groups					
	Black	White	Indian	Coloured		
Ethnic Group	50	82	38	91	261	Count
	19	31	15	35	100	Percent

		Ethnic Groups				Total	Percent
		Black	White	Indian	Coloured		
Age of Respondent	Between 18 and 30 years	9	31	8	17	65	25
	Between 31 and 40 years	8	20	9	22	59	23
	Between 41 and 50 years	22	9	11	31	73	28
	Between 51 and 60 years	9	12	6	9	36	14
	Between 61 and above	2	10	4	12	28	10
Total		**50**	**82**	**38**	**91**	**261**	**100**

		Ethnic Groups				Count	Percent
		Black	White	Indian	Coloured		
Gender of Respondent	Male	31	42	17	46	136	52
	Female	19	40	21	45	125	48
Total		**50**	**82**	**38**	**91**	**261**	**100**

		Ethnic Groups				Count	Percent
		Black	White	Indian	Coloured		
Occupation of Respondent	Farmer	25	34	9	14	82	31
	Tourism / Real Estate	0	4	6	28	38	16
	Government Employee	9	4	8	22	43	17
	Business / Retail	12	22	10	16	60	22
	Construction / Maintenance	3	13	4	11	31	11
Total		**50**	**82**	**38**	**91**	**261**	**100**

		Ethnic Groups				Count	Percent
		Black	White	Indian	Coloured		
Income of Respondent	Below R12,000	3	3	0	29	35	13
	R12,001 to R150,000	33	30	17	36	116	44
	R150,001 to R1,000,000	10	35	11	14	70	27
	R1,000,001 to R5,000,000	4	5	9	8	26	11
	above R5,000,000	0	9	1	4	14	5
Total		**50**	**82**	**38**	**91**	**261**	**100**

		Ethnic Groups				Count	Percent
		Black	White	Indian	Coloured		
Education of Respondent	Below Matric	5	0	0	0	5	2
	Matric	23	24	16	39	102	39
	Bachelor's Degree	10	27	8	4	49	19
	Post Graduate Degree	2	20	4	6	32	12
	National Diploma	10	11	10	42	73	28
Total		**50**	**82**	**38**	**91**	**261**	**100**

7.6 Statistical Analysis and Findings Across the Ethnic Groups

Analyses are based on 261 participants who took part in the quantitative study. To investigate the research questions empirically, the Kruskal Wallis test was used to identify and compare the effects of the key factors on public perception concerning shale gas development. The results, findings and theoretical considerations are presented below:

7.6.1 Level of Social Acceptance and Risk Perception

Social influences have been shown to shape public acceptance of shale gas development. The KW test was used to assess the social context/behaviour towards shale gas development across the four ethnic groups. The Kruskal-Wallis test revealed a strongly significant difference in the extent to which sociocultural factors influence perception about shale gas development at $p < 0.05$ among the ethnic groups (Table 32). To find out whether there is an underlying difference between the groups, the pairwise comparison test was carried out. Table 32 shows the result of the pairwise multiple comparisons among the ethnic groups to assess the differences in acceptance. The null hypothesis (H_o) for each of the pairwise multiple comparisons is the chance of observing a random value in the first sample or ethnic group larger than a random value in the second ethnic group. Given that the Kruskal-Wallis Test statistics are highly significant ($H(3) = 173.59$; $p < 0.050$), the null hypothesis is rejected. It was meaningful to apply the post hoc test to analyse the underlying difference across the groups.

7.6.1.1 Descriptive and Pairwise Comparisons

The result of the survey data revealed that 56 % of the participants are opposed to shale gas development while 53 % of the participants showed support of the shale technology, 2 % of the participants were undecided (see appendix 9, Fig.54 and Table 33). The data analysis showed a significant difference in perception and the extent to which the public evaluate the risks and benefits caused by shale gas development. The result showed that the four ethnic groups differed in their perception of shale gas development.

The White and Indian groups expressed strong opposition of the shale technology based on environmental concerns regarding the potential impact on human health and the environment (e.g., impact on water and air quality), while the Black and Coloured groups showed strong support of the shale technology based on potential economic benefits ranging from job creation and boost to local economic growth.

Table 32: Independent Test on Public Acceptance of Shale Gas Development

	Are you in support of fracking/shale gas development in the Karoo
N	261
Median	2.0000
Chi-Square	173.594
df	3
Asymp. Sig.	.000

Table 33: Pairwise Comparisons- Are you in Support of Shale Gas Development

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
White-Indian	-8.357	14.157	-.590	.555	1.000
White-Coloured	-122.367	10.956	-11.169	.000	.000
White-Black	127.175	13.026	9.763	.000	.000
Indian-Coloured	-114.010	13.911	-8.196	.000	.000
Indian-Black	118.817	15.593	7.620	.000	.000
Coloured-Black	4.808	12.758	.377	.706	1.000

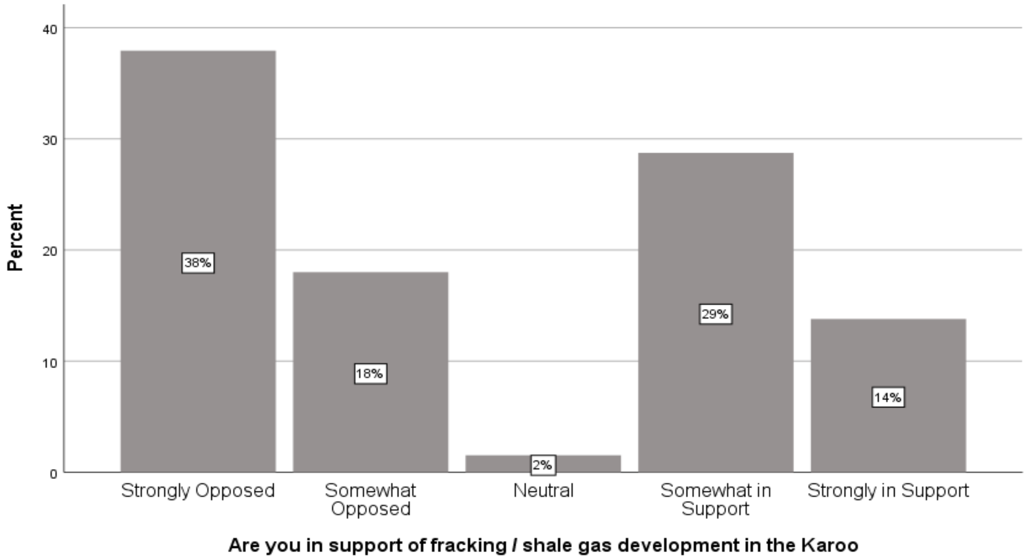

Figure 54: Public Response Regarding Level of Support of Shale Gas Development

7.6.2 Preferred Source of Energy

The development of fossil fuel has proven to be effective drivers of economic growth and energy generation; however, fossil fuels have been depicted as damaging and harmful to the environment. This study analysed public energy preferences in comparison to natural/ shale gas. The result revealed that the White and Indian groups have considerable awareness and recognised that renewable energies (solar and wind power) are a non-polluting energy source compared to shale gas and other alternative energy sources. The White and Indian groups supported renewable energies as the best option for electricity generation. The two groups agreed that expanding the supply and growth of renewable and eco-friendly energy sources is the logical pathway towards a decarbonized and sustainable future. There was mixed support among the Black and Coloured participants for fossil fuel and renewable energy development based on the perception that the shale technology will mitigate short term climate change effects and other benefits related to economic growth and energy independence.

The outcome of the Kruskal Wallis test provided a significant difference (p <0.05) across the ethnic groups, proving a rejection of the null hypothesis H (3) =16.65; p<0.05 (Tables 34 and 35). The post hoc analysis test showed that the White and Indian groups preferred renewable energy while the Black and Coloured group showed a strong preference for natural gas development.

7.6.2.1 Descriptive and Pairwise Comparisons

The result of the descriptive analysis showed that 71 % of the participants preferred renewable (solar and wind) energies, 14 % natural gas, 12 % coal and 3 % nuclear power (see appendix 9, Fig.55, Tables 34 & 35). This is unsurprising, given that the White and Coloured groups are concerned about the impact of energy development on the environment compared to the Black and Coloured groups who support shale gas based on the economic benefits.

Table 34: Independent Test on Preferred Source of Energy

	What is your preferred energy source
N	261
Median	3.0000
Chi-Square	16.654
df	3
Asymp. Sig.	.001

Table 35: Pairwise Comparisons- What is your preferred source of energy

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Black-Coloured	-.102	12.670	-.008	.994	1.000
Black-Indian	-48.365	15.486	-3.123	.002	.011
Black-White	-49.413	12.936	-3.820	.000	.001
Coloured-Indian	48.263	13.815	3.493	.000	.003
Coloured-White	49.311	10.880	4.532	.000	.000
Indian-White	1.048	14.059	.075	.941	1.000

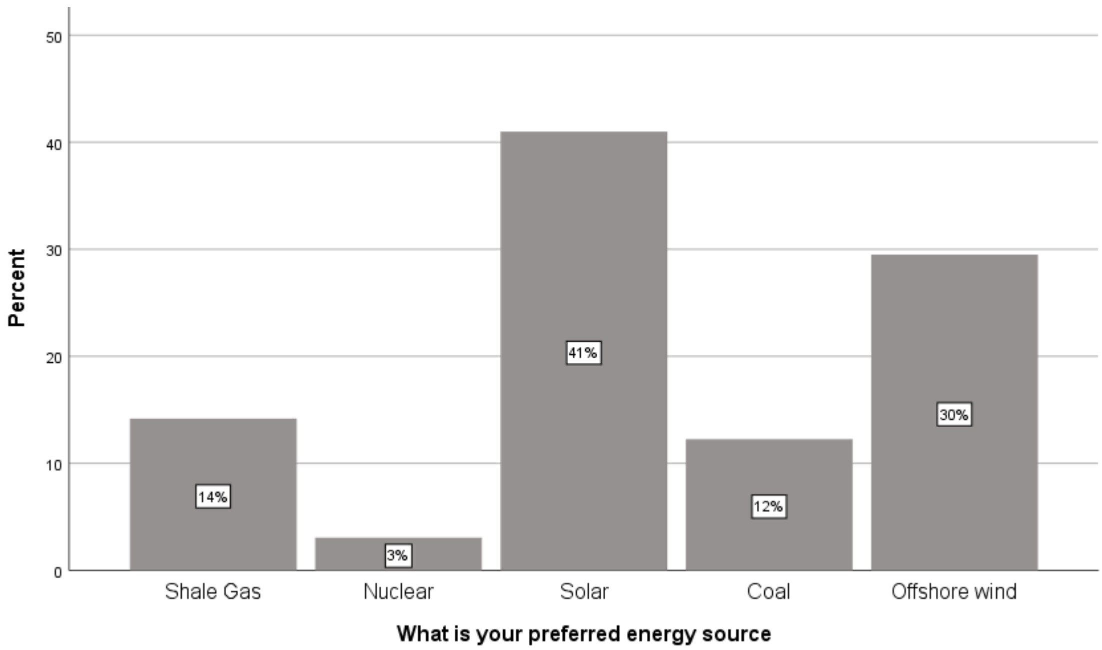

Figure 55: Public Response Regarding Preferred Source of Energy

7.6.3 Sense of Place -Attachment

The growing demand for the development of sustainable energy sources has furthered the interest to understand the underlying factor influencing community response or perception to local energy developments. This study investigated how place attachment factored into community perceptions of shale gas development in the Karoo. Participants from the White and Coloured groups (mainly landowners) expressed concern about preserving cultural and land spaces compared to the Black and Indian social groups who are mainly non-landowners. The result further demonstrated the need to determine how locally/ indigenous populations perceive shale gas development with regards to the sense of place and its effects on NIMBYism.

Kruskal-Wallis test of mean comparison among the ethnic groups showed significant differences $p<0.05$ in response to the question regarding the effect of shale gas development on place attachment (Table 36). No significant differences were observed among non-landowners (Black, and Indians) (Table 37) (see appendix 9). A post hoc comparison test showed that White and Coloured groups are inclined to migrant out of the area licensed for shale gas development compared to Black and Indian groups due to environmental concerns and impact to health. In addition, the White and Coloured group showed a higher level of distrust of the government regarding potential land acquisition/ expropriation for shale gas development than non-landowners (Black and Indian).

7.6.3.1 Descriptive and Pairwise Comparisons

When the participants were asked if they are comfortable living in an area licensed for shale gas development, 54 % of the participants believed that they were not comfortable and acknowledged the likely impact of shale gas development while 16 % feel comfortable living in the area, 30% of the participants were undecided (Fig. 56). The reference to "Not In My Back Yard", or "NIMBY" underly public resistance to shale gas development in the local community. Although the concerns vary between the White and Indian groups who express concerns about living in marked for shale gas development and the Black and Coloured group who felt comfortable with shale gas development. However, "Not In My Back Yard", present an underlying theme that will need to be addressed in the planning and development of shale gas resources in the Karoo.

$$H(3) = 17.54; p < 0.050$$

Table 36: Independent Test on Place Attachment/ NIMBY

	Fracking will occur in or near my neighbourhood*
N	261
Median	4.0000
Chi-Square	17.535
df	3
Asymp. Sig.	.001

Table 37: Pairwise Comparisons- Fracking will occur in my neighbourhood.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Black-Indian	-30.372	15.661	-1.939	.052	.315
Black-Coloured	-31.188	12.813	-2.434	.015	.090
Black-White	-65.909	13.082	-5.038	.000	.000
Indian-Coloured	-.815	13.971	-.058	.953	1.000
Indian-White	35.537	14.218	2.499	.012	.075
Coloured-White	34.721	11.003	3.156	.002	.010

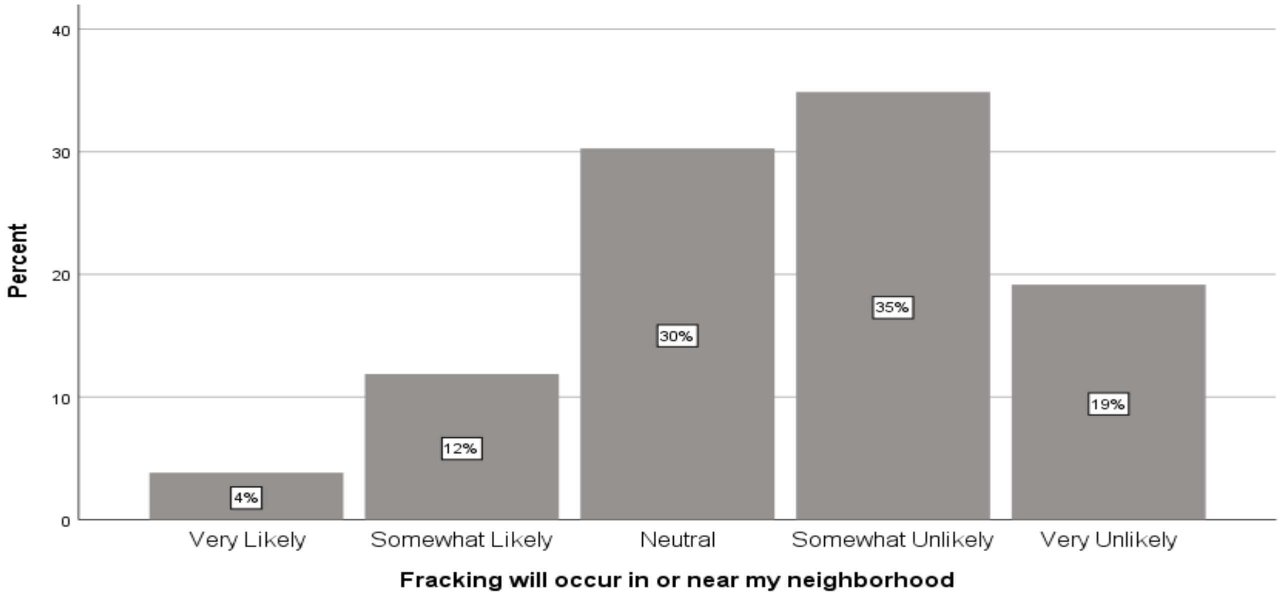

Figure 56: Public Response Regarding Sense of Place

7.6.4 Stakeholder Engagement and Social Representation

Within the energy discourse literature, it is argued that effective social representation and stakeholder engagement plays a significant role in building instructional trust with the local community and improving the social acceptance of shale energy development. Independent Kruskal Wallis tests were performed to compare and identify whether there are significant differences among the groups. There were significant group differences ($H(3) = 46.95$; $p < 0.05$) between the groups (White and Indian) and no significant difference between Black and Coloured groups (Table 38).

A pairwise comparison showed the level of stakeholder participation in shale gas discussions is in the average of 2.11 for the White and Indian groups, significantly lower than the Black and Coloured ethnic group 4.54 (Table 39). The mean ranks of stakeholder engagement and public participation are presented in appendix 8. Based on the KW results shows that participants who are satisfied with the level of stakeholder engagement are likely to support shale gas development compared to participants who feel otherwise. The level of a social group involved in the decision-making process of shale gas development is significantly related to the level of public acceptance of shale technology and describes the extent to which the community engages with all aspect of the shale discourse.

7.6.4.1 Descriptive and Pairwise Comparisons

This study conceptualizes that social acceptance of shale gas development constitute a continuum of public participation processes that guide the development of shale technology. 54 % of the participants expressed dissatisfaction with the state of current public engagement while 26 % demonstrated satisfaction and 21 % were undecided regarding the level of citizen's participation in the decision making of shale gas development (see Fig. 57 appendix 9). This predictive model can be used by policymakers to improve community engagement in achieving a social license to operate.

Table 38: Independent Test on Stakeholder Engagement

	I approve government/oil companies (public) engagement strategy concerning fracking
N	261
Median	4.0000
Chi-Square	46.945
df	3
Asymp. Sig.	.000

Table 39: Pairwise Comparisons- Level of Engagement Strategy

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Indian-Coloured	-2.901	14.108	-.206	.837	1.000
Indian-Black	48.149	15.815	3.045	.002	.014
Indian-White	79.459	14.358	5.534	.000	.000
Coloured-Black	45.247	12.939	3.497	.000	.003
Coloured-White	76.558	11.111	6.890	.000	.000
Black-White	-31.310	13.211	-2.370	.018	.107

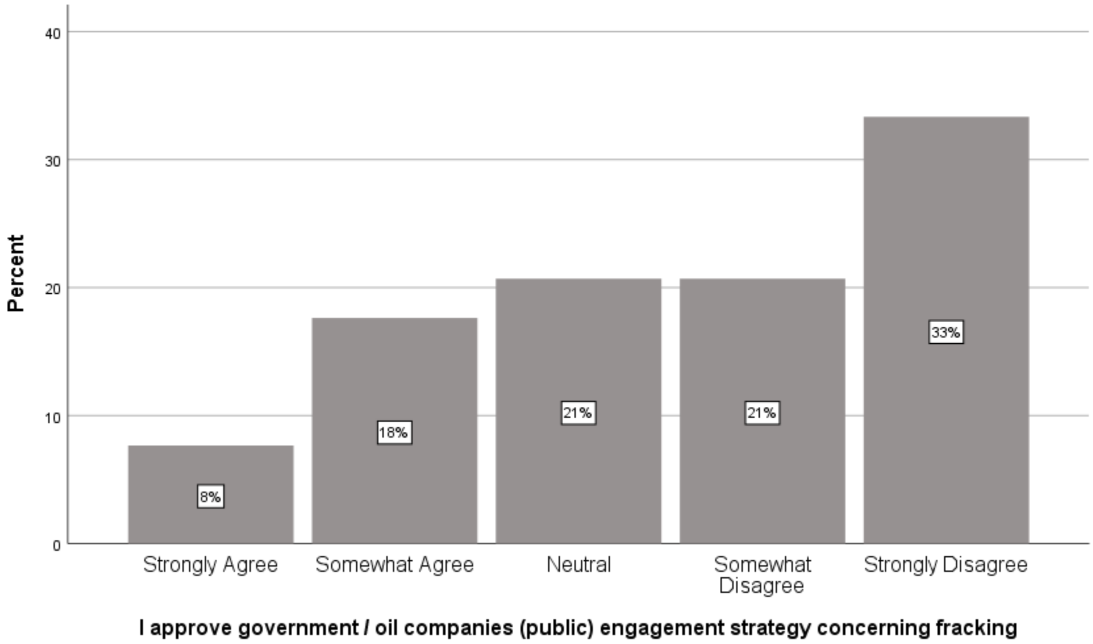

Figure 57: Public Response Regarding Engagement Strategy

7.6.5 Effects of Expert Opinion on Public Perception

The lack of scientific consensus about shale gas development and hydraulic fracking has been shown to erode public trust in shale technology. This is problematic both from a policy-making and theoretical viewpoint is driven by the lack of coherent messaging, poor public awareness and significant scientific uncertainty regarding the cost benefits associated with shale gas development. Analysis of the quantitative data using a Kruskal-Wallis test revealed a significant effect H (3) = 45.82; p <0.05 among the groups on the effect of expert opinion on public perception and the influence in influencing the social acceptance of shale gas development (Tables 40 and 41). Analyses of aggregated data suggested that the perceived threat of shale gas development and trust in institutional and regulatory bodies were important considerations influencing perceived risks. In terms of risk sensitivity, the experts demonstrated an ambivalence to risk likewise the public who showed variation to risk according to their ethnic groups.

7.6.5.1 Descriptive and Pairwise Comparisons

In terms of using expert opinion to assess the risk of shale gas development, 48 % of the participants acknowledged that expert's opinion regarding the risks of shale gas development is significantly high compared to 29 % who believed experts opinion on risks are low and 23 %

are undecided. Environmental concerns such as the impact on domestic water and air quality were the highest predictors and most influential of risk concerning shale gas development than social and economic impacts. Excessive withdrawal of water for shale gas activities was the most influential variable underlying public perception about shale gas development. There was consensus about the influence of environmental impact among the White and Indian groups. Policy decision makers will need to prioritise public concerns and design appropriate intervention to mitigate the impacts (Fig. 57).

Table 40: Independent Test on Expert Perspective

	What is the expert view on hydraulic fracking/shale gas development*
N	261
Median	2.0000
Chi-Square	45.815
df	3
Asymp. Sig.	261

Table 41: Pairwise Comparisons- Expert view regarding shale gas development

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
White-Coloured	-81.614	10.590	-7.706	.000	.000
White-Indian	-106.932	13.684	-7.814	.000	.000
White-Black	115.098	12.591	9.141	.000	.000
Coloured-Indian	25.318	13.447	1.883	.060	.358
Coloured-Black	33.485	12.333	2.715	.007	.040
Indian-Black	8.166	15.073	.542	.588	1.000

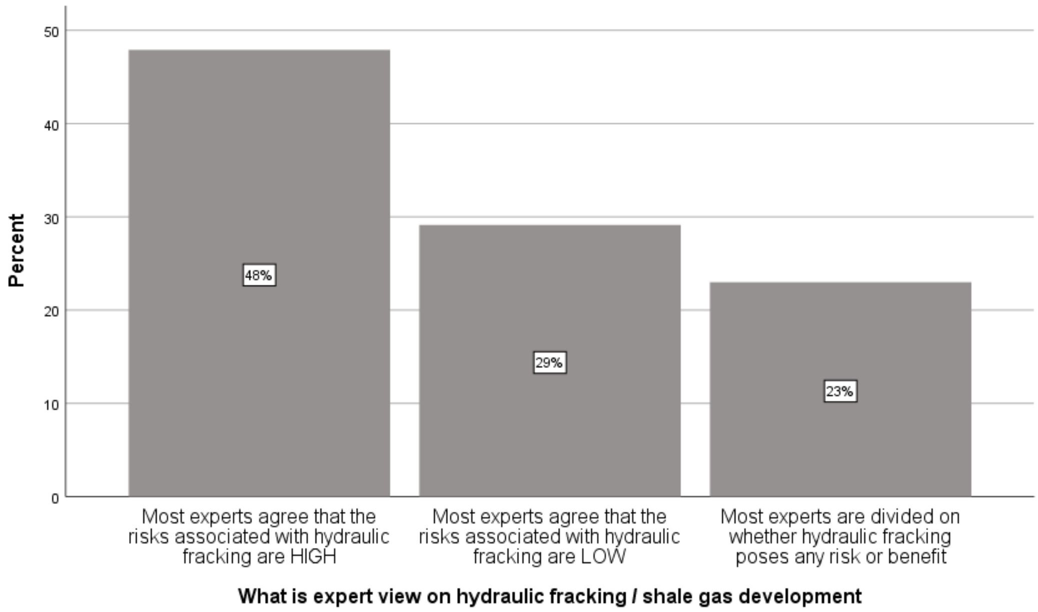

Figure 58: Public Response Regarding Expert Opinion

7.6.6 Moratorium on Shale Gas Development

Given the long-term microeconomic benefits and environmental uncertainties of shale gas development, it was critical to explore public behaviour regarding the current moratorium of shale technology. Although the Kruskal Wallis Test revealed statistical significance $p<0.05$ among the White and Indian ethnic groups ($H(3) = 65.81$; $p < 0.05$) with support for the current moratorium/ impasse in the short-term pending further scientific investigation regarding the socioeconomic and environmental impacts of the technology (Tables 42 and 43). The Black and Coloured groups did not support the current moratorium. The participants believed that the lifting of moratorium will enable evidence-based assessment of the impacts until further studies can provide clarity on the impact of shale gas development in the Karoo. There was less public (Black and Coloured) support against the current suspension of exploration activities in the Karoo.

7.6.6.1 Descriptive and Pairwise Comparisons

47 % of the participants support the current moratorium, 32 % opposed the temporary ban while 21% were neutral. (Fig. 57). The participants who support the current moratorium believe that renewable energy will continue to contribute to South Africa energy mix. On the basis of the current scientific evidence and moratorium, the central government took a presumption stance against issuing exploration permit until public consent is secured and further studies for shale gas development is compelling for future application.

Table 42: Independent Test on Moratorium

	I support the current temporary ban on fracking in South Africa*
N	261
Median	3.0000
Chi-Square	65.812
df	3
Asymp. Sig.	.000

Table 43: Pairwise Comparisons- Perception of Moratorium

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
White-Indian	-26.066	14.448	-1.804	.071	.427
White-Black	90.597	13.293	6.815	.000	.000
White-Coloured	-124.674	11.181	-11.151	.000	.000
Indian-Black	64.531	15.914	4.055	.000	.000
Indian-Coloured	-98.608	14.197	-6.946	.000	.000
Black-Coloured	-34.077	13.020	-2.617	.009	.053

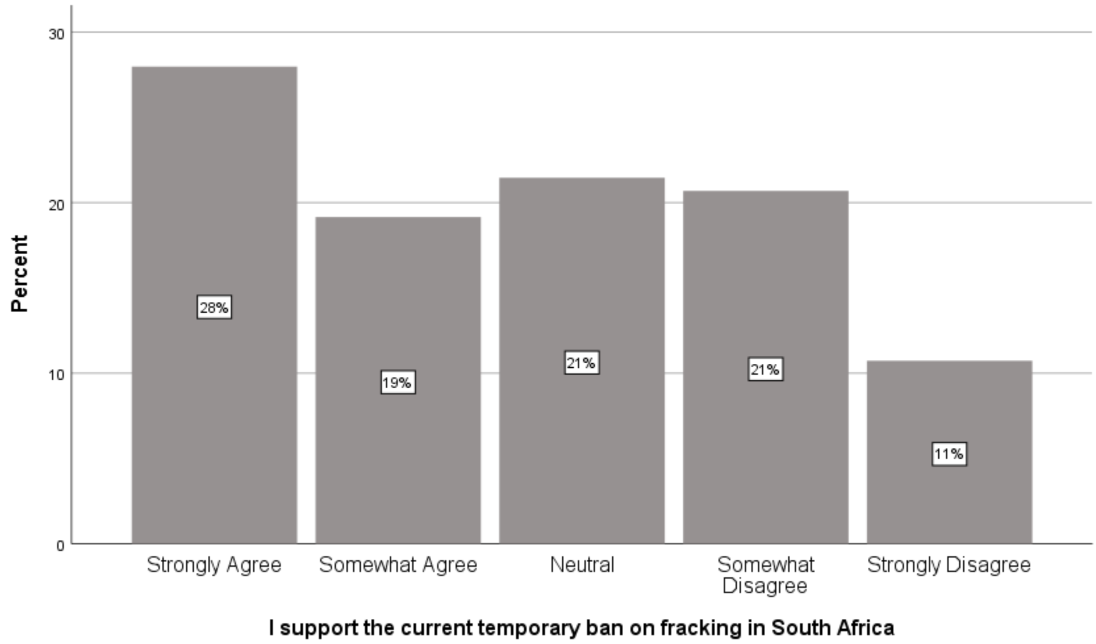

Figure 59: Public Response Regarding Moratorium on Shale Gas Development

7.7 Eta-Squared: Effect Size for ANOVA

A measurement of the size and magnitude of the effect using the eta squared (SPSS) was performed to communicate the practical importance/ significance of the result and establish the proportion of variance that is explained by the group. Notice in Table 44 that the p values (0.00, 0.00, 0.00, 0.015, 0.00, & 0.10) indicate that there were was significant effects (i.e., p values below .05) for level of awareness, sense of NIMBY, preferred source of energy, effects of expert view, perception of current moratorium and major concerns associated with shale gas development. Note also that there was not sufficient power to detect effects size (i.e., .155, .087, .089, .032, .229 & 0.282 were small to moderate). A better designed replication study with a larger sample size might be justified for a future study, which is reasonable given the very small sample size of 261 used for this current study.

Table 44: Results of the ETA Analysis with SPSS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Awareness	52.811	6	8.802	7.776	**.000**	**.155**
NIMBY	29.475	4	7.369	6.068	**.000**	**.087**
Preferred Energy	30.356	4	7.589	6.268	**.000**	**.089**
Expert View	10.897	2	5.448	4.267	**.015**	**.032**
Moratorium	77.982	4	19.496	19.024	**.000**	**.229**
Major Concerns	95.941	8	11.993	12.366	**.000**	**.282**

7.8 Discussion and Findings

Shale gas development like any large industrial development has the potential to induce environmental and socioeconomic impacts in the local community where its situated. The extent of these impacts such as competition with domestic water supplies, contamination of surface and subsurface water bodies, air quality impact, land/ seismicity, strain on social services, shortage, and unaffordable housing as result of population growth, increase in crime, influx of migrate worker force will depend on the scale and speed of shale gas development. Other impacts such as disruption of the community/ social character and impact on place-based values will likely inhibit the planning, development, and future of the shale industry. These concerns or issues are likely to impact some residents negatively. Additionally, positive impacts such as increased employment, local economic growth, access to affordable energy, energy independent and mitigation of environmental impact in terms of greenhouse gas reduction enable individuals to support the development of shale gas.

This study explored expert and public perception of shale gas development in South Africa. The study showed mixed levels of support between the experts and the public. 81 % of the experts showed support of shale technology while 56 % of the public demonstrated opposition about shale gas development. The data analysis revealed that experts believed that shale gas development offers South Africa the opportunity to be energy independent, improve economic growth, generate significant employment prospects for the growing population and improve electricity generation. The experts acknowledged that natural gas is the cleanest fossil fuel and shale gas can provide an efficient and low cost “low Carbon Bridge” while the move to renewable energy future. However, 19 % of the experts opposed the development of shale gas development given the range of geological and environmental uncertainties associated with extracting the Karoo shales. The experts noted that the complexity of dolerites in the Karoo basin and transient shale well performance could reduce the potential of the Karoo Basin. On the basis of geological uncertainties, 92 % of the experts support the suspension/ moratorium of shale gas development to enable evidence-based assessment of the impacts. This position aligns with the precautionary policy of the South Africa government on further exploration activities. 8 % of the experts believed that moratorium would hinder the transition journey and undermined the economic and energy growth of South Africa.

As discussed, 56 % of the public mostly White and Indian groups showed strong opposition of shale gas development while 53 % of Black and Coloured groups supported the shale technology. The White and Indian groups place a higher emphasis on environmental impact over economic benefits of shale gas development. The White and Indian groups highlighted the impact of shale gas development on the already stressed water supplies in the Karoo and potential contamination of ground and subsurface water sources. The Black and Coloured groups believed that shale gas development will generate significant jobs and improve the economic landscape of the Karoo. The group believed that the economic benefits of shale gas development outweigh the environmental impacts. on the flip side, the White and Indian groups perceived that the environmental risks outweigh the economic benefits. It appears that response to the social acceptability of shale gas development, level of institutional trust and position on the current moratorium was moderated by social identity. Majority of the White and Indian groups stood against shale gas development while a large proportion of the Black and Coloured groups supported shale gas development. However, when natural gas was regressed against coal power, all the groups demonstrated that the transition journey to renewable energy is critical to reduction of greenhouse gas emissions using natural gas than coal energy.

The impact of place-based values and the influence of NIMBY was critical to the social acceptability of shale gas development among the ethnic groups. The influence of NIMBY offered two conclusions, proximity to the proposed licensed areas of shale gas development aligns to the local context and appeared to influence the perception of the White and Indian groups to form a negative attitude and strong opposition/ resistance to shale gas development while the nature of NIMBY among the Black and coloured groups stems a positive attitude and support of the shale industry. It is necessary to clarify the influence of NIMBY in the planning of shale gas development in order to improve our understanding of the social construction of individuals/ social groups within the local community and the way in which public opinion is elicited concerning shale gas development which can be developed in future studies.

Exploring public awareness and acceptance towards shale gas development are critical for providing understanding necessary for campaigns and public information programs to enhance greater knowledge and awareness of shale gas development. The study indicated a high level of awareness towards shale gas development with the public, however, the source of information was mainly non peer reviewed sources, from local newspapers (24.4 %), family/ friends (24.5 %), non-fracking internet sources (15.2 %), Television news (14.2 %), social media (10.3 %) and scientific books/ magazines (4.0 %). The deficit model (DM) used by scientists and policy makers to describe energy projects based on the belief that the public lack scientific literacy and knowledge and therefore undermine industrial projects is critiqued by the findings of this study (Wynne, 1982; Phillips and Beddoes, 2013). The DM obscures the critical social elements and processes in which the public understands scientific facts and how technological innovation works in their lives and local setting. The DM theory is problematic in this context given that the public constructed their meaning of shale gas development from their own core values including personal and local/ social experiences. It is conceivable that these values also influence the perception of scientists. The field of science and technology are not value free or unbiased operations but built on numerous studies that demonstrates biases regarding the issues that are researched, the questions that are designed and asked and the way the data and observations are interpreted. This study proposes an inclusive consultative and public participation framework that include all stakeholders – scientist, policymakers, industry, interested and affected parties to better understand the nature of shale gas development and its impact on the local population.

7.9 Conclusion

The results of this study have significant implications at the local level and reveal the broader disparities and commonalities between the experts and public perception of risks and benefits concerning shale gas development. The experts and public consist of individuals with persuasion moulded through personal, collective, and social experiences. The experiential knowledge allowed both expert and the public to have a strong opinion in issues associated with shale gas development which may translate to different persuasions or outcomes about the risks and benefits of the shale technology. While a significant portion of the experts demonstrated a positive perception and support of shale gas development, a substantial section of the public showed a negative perception and opposed the development of shale gas in the Karoo.

Chapter 8: Conclusions and Recommendations

8.1 Introduction

South Africa has a significant shale gas reserve which could improve the economic growth of the country and facilitate the decarbonisation of the energy system. Despite significant advances in the last decade, the development of shale resource produces benefits both to the local community and to the society/ country at large, but adverse impacts from the development of shale resource are frequently experienced by the local community. Additional complexity is finding a balance/ trade-off between the risks and benefits of shale gas development. More significantly, expert, and public perception are critical in understanding the local benefits and impact of shale gas development using an interview and survey questionnaire-based instrument. The opinion of experts is essential for ensuring the design and deployment of energy policy. Understanding the underlying drivers of public perception is important as public attitude can influence the adoption of the shale technology.

The interview was administered to a sample of 26 experts with participants from policy makers, industry practitioners comprising of geologists, drilling, and reservoir engineers. 261 survey questionnaires were used to sample public perception across the diverse social groups (Black, Coloured, Indian, and White) in the Karoo using a range of sociodemographic, beliefs, norms, and value considerations. It was possible to analyse the data to understand the perceptions of experts and the public about the risks and benefits of shale gas development. The participants drew on international and local context as well as place-based values and experiences in their responses to the questions on uncertainties and benefits of shale gas development allowing new themes and insights to emerge with regards to the underlying factors shaping individual perceptions and deeper societal concerns.

8.2 Variation in Perception between Technical Experts and Policymakers

The lack of consensus among experts regarding the risks associated with shale gas development has been found to distort energy policy making, largely responsible for the lack of public trust in siting shale gas development project in the local community. Understanding the diverging perception among experts has become a central focus of inquiry across a range of energy related disciplines which informs the way policy options are designed and translated into action (Frey et al., 2017). Integrating divergent perception in decision making provides the opportunity to appraise the current theoretical assumptions and improve the quality of the evidence base in policy formation. Applying the perception framework to energy development, ensures that government and energy regulators adopts a realistic perspective of the risks associated with shale gas development to achieve a better policy outcome. The main objective of the qualitative study was to identify the underlying drivers of expert perception towards shale gas development and the way it is reflected in the South Africa shale discourse. The study found that the attitude of expert regarding risks assessment is influenced by context and choice options (Kusev et al., 2020). In most cases, heuristics create personal, or group biases to the way people respond to energy issues.

Responses to these questions by the participants provided clarity regarding the local level impacts and the way experts frame their perception regarding shale gas development. Other than these, experts assess risks differently and their perception demonstrate a causal influence of the following factors:

1. Lack of baseline data to make a sound empirical judgement
2. Inconsistent standard of measurement
3. Inadequate theoretical understanding of the operational mechanism and processes involved in shale gas development
4. Influence of contextual norms, culture, and political factors

These gaps are responsible for the divergent opinion and behavioural biases among experts which characterizes the way the scientific community is pitted against itself and the public. The study demonstrated that the perception of expert varies according to their professional background (results have been presented in tabular (Tables 21 to 30) form for each question showing the variance in perception. The technical experts (geologists and engineers) were more ambivalent in their responses about the risks and acceptance of shale gas development compared to the policy makers who showed low risk and significant support of shale gas development. The study demonstrated that the professional background of the experts plays a key role in shaping their perception and inform how the communication of risk related to shale gas development should be constructed. Policymakers develop an eclectic perspective of issues and tend to support government priorities informed by current political narratives rather than informed by the evidence base (Cairney, 2016; Kenny et al. 2017; Oliver and Pearce, 2017; Mayne et al., 2018).

8.3 Landscape of Expert and Public Perception

The influence of expert and public perception is playing an increasingly important role in energy development. In recent years, the study of public opposition or resistance to complex energy systems like shale gas development has been expanded by research on the drivers of expert and public perception about the risks and benefits of the shale technology (Ying and Sovacool, 2021). The attachment to the values and benefits of energy development, meanings and influence of the local environment, sociocultural construct and sense of place is shaping the way energy is perceived and implemented in the local setting. Subjective judgements of individuals and reactions to the risks and benefits of energy developments can influence an individual's perception. Consequently, the role of perception in energy development is acknowledged as a scholarship that ensures that the opinions and values of experts and the public and 'all interested and affected parties' are represented and reflected in policy formulation, planning and development of energy resources (Boudet et al., 2014). The perception of the individual is not only shaped by the individual core/ personal values, including direct and indirect experiences but also conditioned by the prevailing socio-cultural beliefs and specifically the individual associated to the social identity of the local community which are reflected as distinct attributes of the different sociocultural groups (Black, Coloured, Indian, and White) in the Karoo (Issah and Umejesi, 2019). This study argues that the association/ affiliation of the individual to the social identity (the individual derives self-worth and meaning from social identity; the strengthened by association and shared decision of social groups) of the community is critically important in shaping the perception of the individual about the risks and benefits of shale energy development (Quiñones-Rosado, 2010). Therefore, the shared decision/ belief of social groups (Black, Coloured, Indian, and White) influences the individual perception about the social acceptability of the energy system (Joffe, 2003; Issah and Umejesi, 2019). This position aligns with Yardley's (1997) theoretical consideration of risk as both material and socially constructed.

The disjunction between experts and public perception cannot be explained as a simple limitation of relevant information and knowledge gap, often implied by industry experts and policy makers as the deficit model (DM). The DM highlights that public resistance to industrial and energy development stems from "scientific ignorance" - the lack of knowledge and information in energy development. The assumption is that access of the public to relevant information and improved scientific literacy reinforces positive perception and social acceptance of energy development. However, this belief is problematic as studies have shown that some members of the public possess adequate knowledge and experiences of science and technology, at the same time, we find that the perception of the individual is shaped by local (social, cultural, and political) experiences (Bucchi and Neresini, 2008). Therefore, it is important to consider public perception/ knowledge in decision making about complex energy systems instead of relying exclusively on technocratic form of decision making (Fischer, 2000). The features of scientific knowledge or technological development is not value free or unbiased in their design and deployment. In the same way, the knowledge and experiences of experts are shaped by numerous studies built upon by personal biases and subjective opinions such as the collection of scientific data and the way observations are interpreted, the design of technological innovation and the interest that it serves (Bucchi and Neresini, 2008; Hackett et al., 2008; Sismondo, 2010). This study demonstrated that both experts and public perceptions are shaped by broader influences such as personal, social values and biases in multiple ways. The study advocates the incorporation of social representation and participation in the planning and development of energy systems in order to identify the values of experts and public and integrated into decision making. Beck et al. (1992) referred to experts are laypersons in issues related to social and political judgement. Against this background, the author advocated democratic policymaking framework that bring both scientific and public/ social judgement together in order to facilitate learnings and foster the representation of communities in decision making.

8.4 Overview of the Study

How risk is constructed and perceived by different public and expert groups in the context of shale gas development in South Africa is poorly understood and open to argument. To a certain degree, this is due to the different theoretical viewpoints from which risk perception is explored. While extant theoretical perspective is valuable and provide some level of understanding and interpretation of risk perception.

This study aims to explore the interplay of factors shaping risk perception and the disjunction between expert and public perspective within the context of shale gas development in the Karoo. This study recognises the role public perception plays in shaping energy policy and the social acceptance of shale gas development.

This study used qualitative and quantitative to explore and analysed the factors shaping experts and the public perception to specific risks and hazards of shale gas development. The underlying framework of the methodology used for this study is to segregate experts and public perception on the basis that the way expert construct and respond to risk is different from the public. Clearly the effect of culture will be relevant in our understanding in the way risk is constructed by the social groups in the Karoo (Douglas and Wildavsky, 1983; Taylor-Gooby, P., 2004) which regulates their perception and attitude towards shale gas development. The recognition that trust plays a role in shaping the perception of individuals is emphasised in the study, given that trust is culturally influenced or determined (Taylor-Gooby, P., 2004).

Public concern about the environmental impact of shale gas development is negatively associated with public attitude towards shale gas development, while economic growth and job creation tended to shape positive attitude towards the shale technology. The study also found that increased trust by the public on institutional bodies has a positive impact on public perception and support of shale gas development, verse versa.

8.5 Revisiting the Research Objectives and Questions (Research Question, RQ)

The research aims, objectives and problems were identified in chapter one of this study and the literature review completed in subsequent chapters 2, 3, 4 and 5. The research questions were used to set the context of this study. The qualitative and quantitative method was combined and used for cross-validation of the findings that reflect the implications of this study. The section below reviews the arguments and findings from the data analysis to answer the research questions (RQ).

8.5.1 RQ 1. What are the perceptions and responses of expert and the public regarding the risks and benefits of shale gas development, does the perceived risks outweigh the potential benefits?

The study discovered that public responses and perception of risks about shale gas development is shaped by a range of contextual and social factors, such as sense of vulnerability, direct and indirect personal and social influences, including information derived from the media, speaking with family and friends (local newspapers (24.4 %), family/ friends (24.5 %), non-fracking sources (15.2 %), television news (14.2 %), social media (10.3 %) and scientific books/ magazines (4.0 %)). The least source of information of the public was scientific publications. It could be argued that the exposure of the public to unscientific sources of information is likely to influence the behaviour of the public. Exposure to credible source of information tend to reduce the level of uncertainties and risks regarding shale gas development. In contrast to public perception, expert drew their inferences, and perception of risk from the scientific sources and shaped their perception from the likelihood or probabilities of the risk occurring. The experts also based their assessment of risk on the environment (Karoo) in which the risk is constructed, perceived, and experienced. Contrary to the experts, the prospect of risk occurring was much more definite and salient with the public than the experts who rely on the estimation of the likelihood of the risk happening.

8.5.2 RQ 2. Is there a direct correlation, differences, or relationship between the measured constructs to behaviour of experts and social groups towards shale gas development?

The study demonstrated relative differences in behavioural responses across the social groups (Black, Coloured, Indian, and White) to risks and scale of impact regarding shale gas development. The differences in perception among the groups depicts the characterisation of the social groups, social processes, and community wellbeing. Studies suggested that the shared values of the community as well as social mobilization shapes the behavioural response of members of the group to risk benefit distribution (Sung and Phillips, 2018; Atkinson et al, 2020). This study found that participants responded to issues concerning shale gas development based on the values and interest of their social affiliation or group. The Black and Coloured groups recorded low scores to each aspect of the risks and uncertainties associated with shale gas development. The groups showed a high level of trust and ability for the regulators to control or mitigate or manage the involuntary risks which further increased their positive perception and support of shale gas development. The group associate shale gas development to job creation and economic benefits. The perception of the Black and Coloured groups tends to correlate with expert's perception of shale gas development (Bickerstaff, 2004; Hansen et al, 2004; Touili et al., 2014; Kane et al., 2014).

The White and Indian groups demonstrated low tolerance to risk and showed that the exposure to shale gas development is harmful and negative. Compared with the Black and Coloured groups, the While and Indian groups recorded high scores on the risk matrix. The group perceived environmental and social risks as greater than economic benefits. Concerns were significant impact on surface and subsurface water bodies, impact on air quality and demographic change from migrant incursion into the Karoo community. The groups demonstrated low level of trust and ability for the institutions to manage the shale industry should it go forward (Renn, 2008). This reason for this mistrust is partly due to a deep and historically established distrust in environmental, social, economic and resource governance in South Africa (Renn & Rohrmann, 2000a). The concept of risk of the White and Indian community did not correlate with expert perception of the impacts of shale gas development.

8.5.3 RQ 3. To what extent does expert judgement affect or compare with public perception about shale gas development?

Addressing the barriers against the social acceptance of shale gas development requires significant changes in public perception. However, the polarization of scientific/ experts' opinion regarding the risks and benefits of shale gas development has amplified doubts and inherent uncertainty about the shale technology further undermining public understanding of shale gas development. The lack of scientific consensus on the merits of shale gas development is underpinned by limited community engagement about the shale technology in a rational way. To better understand how expert/ scientific judgement of shale gas development shapes public perception, the study found that 48 % of the public believed that experts view about the risks associated with shale gas development are significantly high compared to 29 % who believed experts opinion on risks are low and 23 % of the participants were undecided due to lack of scientific consensus or mix messaging.

To reduce the effects of polarization of expert opinion on public perception, studies have demonstrated the need to emphasize the strength of evidence about the issues, particularly when expert consensus does exist (Bolsen and Druckman, 2015; Cook, 2016; Maibach and van der Linden, 2016). For example, studies have revealed that 'perceived expert consensus' is a key factor/ driver of public perception. In a complex and uncertain situation, the public rely on experts for guidance and judgement (Cialdini et al., 2015; Panagopoulos and Harrison, 2016), particularly drawing conclusion from experts is perceived as socially adaptive, as "consensus generally suggests accuracy" (Albarracin et al., 2014). Studies have further demonstrated that people prefer to make their decision based on collective assessment of several experts (Mannes et al., 2014). As such embracing a consensus opinion based on the strength of credible scientific evidence can reduce the distortion of information (the study found that only 96 % of the participants/ public derive their information from non-scientific sources). Furthermore, studies have shown that miss information from 'misleading media balance' and sources of anecdotal testimony can alter the strength of scientific evidence even when consensus opinion has been reached by experts (Aklin and Urpelainen, 2014; Koehler, 2016).

Given the lack of consensus regarding shale gas development, it is critical to establish effective communication with the public and to understand the source of public information and how the information is processed by the public to make their decision. On the other hand, a large body of studies have demonstrated that people can oppose evidence or opinion that is contrary to their prior belief or worldview (Bolsen et al., 2014; Lewandowsky and Oberauer, 2016) For instance, the theory of cultural cognition predisposed that communicating scientific consensus about contested societal matters (especially towards science and the environment) will further exacerbate the polarization of attitude (Kahan et al., 2011; Van der Linden et al., 2017). Other studies have refuted this position and found that scientific consensus can shift public perception positively (Van der Linden et al., 2015; 2015a).

8.5.4 RQ 4. To what extent does the public perception of shale gas development in South Africa compare with the US and the UK?

The US social and environmental landscape favoured the development of shale gas resources transforming the energy and economy growth of the US amidst raising public concerns about the impacts of shale gas development (Metze, 2014; Jaspal & Nerlich, 2013; McGowan, 2014; Lis et al., 2015; Thomas et al., 2017a; Thomas et al., 2017b; Partridge et al., 2017). However, different political and social context have resulted in divergent public perceptions and responses in Europe particularly in the UK where early drilling activities of shale wells in the Blackpool area in 2011 triggered some level of induced seismicity/ small earthquakes (McGowan, 2014; Stephenson, 2016). The lack of public support and raising environmental for shale gas development in the UK is the main reason for the moratoria and policy reversals on exploration activities in the UK. For the most part of Europe, the social license to operate has proved to be difficult due to concerns regarding the impacts of shale gas development on the environment. The nature and lack of transparency of the fracking chemicals, extraction technique (hydraulic fracking) and historical negative legacy of oil and gas industry in degrading the environment makes the shale gas industry at variance with public acceptance in Europe. In addition, the shale resources in Europe are in areas with dense population unlike the shale plays in the US and Canada (Stephenson, 2016).

This study revealed that the public perception about shale gas development in South Africa is divided between the potential economic benefits and the risks posed by the shale technology on the environment. The public weighed more on the cost of shale gas development than the benefits, with 56% of the participants opposed the development of shale gas on four major grounds: contamination of groundwater by stray gas, excessive withdrawal of fresh water for shale gas activities, release of fugitive methane to the atmosphere and the long-term impact on the Karoo ecosystem.

8.6 Review of the Findings

This study proceeds as follows. Firstly, this study reviewed previous studies of risk perception and attitude towards shale gas development and highlighted the gaps in the literature. Secondly, the study presented the justification for the methodology utilized for the study. Thirdly, the result and implications are discussed including the limitations of the study and in the conclusion, the results of the study are summarized.

1. There is evidence of association across the sociodemographic landscape of the Karoo regarding perception and responses to the risks and benefits of shale gas development. Positive relationships were found across the social groups, between Black and Coloured groups on one hand and White and Indian group on the other demonstrating a higher level of community cohesion, social identity, and wellbeing between these groups. These demonstrate the effectiveness of using cultural/ social identity in communicating information and siting the development of shale gas and interventions.

2. The perception of experts in risk analysis and in supporting the development of shale gas development varies from the White and Indian groups but closely related to the Black and Coloured groups.

3. There are uncertainties in the Karoo geology, these relate to the structural mechanism of hydrocarbon generation, accumulation. Studies suggest the lack of evidence regarding some aspect of impacts of shale gas development. However, emphasis will be centred to address these gaps in order to inform decision making.

4. Perceptions of the risks and benefits of shale gas development is culturally important and differ according to the socio-cultural groups and geographical context.

   Key strategies to policy and practice should improve the evidence base of shale gas development, focus on adaptive framework that recognize the representation of the social groups in policy development, planning and development.

8.7 key Considerations and Implications

This section presents the key considerations and synthesis of the findings, segregated into three dominant and interconnected (environmental, economic, and social elements of shale gas development) themes of sustainability. The themes form a complex layer of risks and concerns of shale gas development. This study presents unique perspective regarding the similarity and differences in expert and public perception of shale gas development. The experts, black and coloured participants acknowledged that shale gas development could support South Africa economic growth, generate jobs, provide access to affordable energy, and support the transition to energy independence and mediation of CO_2 emissions. Consistent with the various scenario planning of shale gas development in the Karoo, the experts believed that the base case scenario will ultimately improve South Africa economic growth and energy security.

Conversely, the White and Indian participants highlighted the risks to the environment related to surface and subsurface water contamination and excessive water withdrawals for shale gas activities which could further exacerbate the shortage of fresh water in the Karoo. These findings are consistent with existing studies in the UK (Whitmarsh et al., 2015) and US (Israel et al., 2015; Thomas et al., 2017). The value attached to economic growth, energy security on one hand and environmental risks on the other reflects the ambivalence in attitude and localized context of risk and benefits of shale gas development. The findings of this study indicates that individual perceptions about the risks and benefits of shale gas development is influenced by the subjective evaluation of factors that impacts individual lives and shared values of the community. Institutional distrust was highlighted as a significant predictor shaping the perception of participants across the White and Indian groups.

8.8 Adaptive Policy and Management Practices

Developing an energy policy is generally focused on a clear sustainability agenda and strategy to achieve a balance in the energy trilemma- environmental protection, economic effectiveness, and energy security. Evidence is growing of the global warming potential of energy sources and contribution to the disruption of the earth ecosystem. We understand that greener energy systems are associated with a range of positive and sustainability outcomes and the development of shale gas is recognized as a potential transition fuel to a green future. To some degree, the range of impacts of shale gas development are recognized in literature, however, advances in shale technology and practice need to find ways in which policymakers and regulators can meaningfully harness and develop the Karoo shales sustainably on the strength of best practices, evidence of science and greater benefit to society.

This study builds on global experiences and in particular the perception of the shale industry. This study presented broad assessment of the potential pathways of risks posed by shale gas development and recommend the need to develop an adaptive or contextual mitigation plan to unintended environmental and socioeconomic disruptions.

The need to conduct baseline strategic assessment of the social, economic, and environmental conditions in the planning phase in order to assess the extent to which emerging development when appraise against the baseline can be used to design appropriate mitigate strategies and accomplish the relevant socioeconomic and environmental objectives. Adopting the precautionary principle provide a logical path to developing the Karoo resource in a safe manner (Prpich and Coulon, 2018: Pietersen et al., 2021).

8.9 Defining Hypotheses from the Study

Empirical results from this study were used to formulate the following hypothesis.

H1- risk perception bias is associated with ethnicity/ social groups. Black and Coloured demonstrated a low perception of risk, while White and Indian ethnic groups were concerned with high level of risk. Experts demonstrated less risk about shale gas development. This study hypothesize that perception of low risk correlates with strong support of shale gas development, conversely high risk correlates with opposition of shale gas development.

H2- Variation of acceptability of shale gas development is supported by social identity. Similarities in responses between Black and Coloured groups. Similarities in responses between White and Indian groups.

H3- trust in institutional performance evokes positive influence in attitude towards shale gas development. Verse Versa.

8.10 Limitations of this Study

The limitations of this current study highlight areas for strengthening future research.

Firstly, the sample frame for the qualitative study utilized narrow inclusion criteria for data collection, future studies can broaden these criteria to include the broader community and relevant stakeholders/ interested parties (IP) of shale gas development in South Africa notably environmentalist, oil and gas company representatives, regulatory agencies, and investors in shale gas development in the Karoo.

Secondly, this study used survey data collected from one area of the broader population-Beaufort West. While the data was large enough to characterize the ethnic landscape of the Karoo. The scope and efficacy (generalization) of the findings was limited as it suffered from analysis focused on one area of the Karoo- Beaufort West. The findings of the current study might have been different if data collection was widespread to include more participants and larger Karoo/geographical space. This would have enhanced and improved the generalizable of the findings to the broader South Africa population, including provinces and municipalities.

Fourthly, the qualitative and quantitative data collection was only conducted within a short/ limited period (3 months), this study may not have provided a holistic picture of behavioural changes in perception and the drawing of valid conclusions given that shale gas development is still at the nascent phase of development and under moratorium.

Finally, the methodological context of this study could have been improved by employing a deliberative/ participative form of research methodology, using full-day workshops and focus group discussions that could illuminate a contextual understanding of factors considered most probable to influence the perception of people towards shale energy policy development.

8.11 Closing the Knowledge Gaps

This study identified several factors that shape expert and public perception, broadly classified as ‘independent variables’ characterized how shale gas development is perceived. The factors include contextual, objective knowledge, socioeconomic and environmental values/ views and reflects the multidimensional and complex nature of the forces shaping expert and public perception.

The findings of this study are consistent with the outcome of Dignum et al. (2016). The different social groups in the Karoo and experts endorse and share the same procedural and substantive values (see Figs. 43 & 44). The proponent of shale gas development appeared contented with the current institutional frameworks while opponents of the shale gas development emphasized more stringent and restrictive conditions. With regards to distributive justice, both opponents and proponents expressed the need for equitable benefits and adequate compensation to local communities.

This study supports the premise that risk perception is a multidimensional and deliberative construct. It remained likely that all the participants and social groups arrived at different conclusions of risk perceptions. Although this study found that the risks are more or less important across the social groups with the weakest/ insignificant impacts consistent with the Black and Coloured groups and with the experiential spectrum of participants (i.e., experts). The strongest effects were acknowledged with the White and Indian groups. This study advocates the need to assign a probability value to the possible outcomes of shale gas development in order to assess if the potential risks are acceptable or not (outweighs the potential benefits or verse versa). A precautionary approach is supported in conditions where empirical evidence is inconclusive (Wareham and Nardini, 2015).

Finally, this study found clear evidence supporting our fourth hypothesis that our more nuanced multidimensional measure of risk perception better predicted self-protective behavioural intentions across hazards, which is also consistent with earlier studies (Ferrer et al., 2016). Although deference to scientific enquiry, this study combines sociological theories and rigorous research methodologies to explore the underlying factors responsible for driving the social acceptability of shale gas development in South Africa.

The findings support prior studies concerning the differences and ways in which experts and the public frame their perception about shale gas development (Krupnick, 2013; Thomas et al., 2017; Howell, 2018). In general, the framing of perception is hinged on the balance between environmental concerns and economic benefits. The study found that public perception is broadly subjective, influenced by a range of sociological and contextual factors in contrast to experts' perception which is largely empirical and drawn from technical/ scientific experience.

The study revealed the differing attitude across cultures with distinct individualist worldviews including empirical evidence to support the role of trust, stakeholder engagement, social representation plays in influencing the social acceptability of shale gas development. This study argued that policymaking about shale gas development in South Africa would need to focus on the complex social processes and structures responsible for shaping the behaviours of individuals and ethnic groups.

Two elements of social processes were identified in the study as contributing to future empirical and theoretical work: (a) social representation, which refers to the quality of social integration in decision making and (b) social support, which relates to the sustaining quality of social license to operate. In conclusion, the study discusses the relevance of theory and research in constructing technological niche according to current socio-demographic trends and public policy concerns. Future research is required to explore the contextualization and evolution of these social constructs in time, as the debate about the development of shale gas progressed in South Africa.

8.12 Recommendations and Areas for Further Research

As in any rigorous research endeavour, additional enquiries and questions are raised and made more compelling by new insight and empirical findings generated from the study. The section below highlights some areas for future research.

Further areas for future study are presented below:

1. Future studies could explore the applicability of the measures of risk perception used in this study about shale gas development at different temporal and spatial settings to better understand the sensitivity of the risks and variation of impacts across the groups.

2. Given that the experts in this current study identified the potential pathways for contamination. However, the public (understanding) did not provide any distinction between the risk from direct shale gas activities and those derived from the extraneous situation. A new study needs to further explore the potential risks, research the mitigations, and best practices to further diminish the potential risks and uncertainties from a subset of the pathways.
3. Another area for further studies should be focused on a better understanding of the cost and benefits of shale gas development to local communities. Examine how to maximise the cumulative benefits concerning mitigating the impact of boomtown effects, present a critical step toward making shale gas development, viable, sustainable, and socially acceptable to the local community.
4. Several emerging subjects have yet to be explored to fully characterize the potential impact on human health and habitat fragmentation.
5. The current study took a broader look at the perception regarding regulatory and resource governance, however, important questions emerged about the role local/ social representation plays to enhance public trust and decision making.

6. It is valuable to further explore and monitor the underlying factors shaping expert and public perception from the longitudinal point of view as a predictor to align public perception to policy-making and social representation.

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Appendices

Appendix 1: Ethical Considerations and Approval

Irene, Julius O

From:	Renshaw, Layla M
Sent:	Thursday, June 13, 2019 13:27
To:	Irene, Julius O; SEC FREC NB; Pittom, Piers E
Cc:	Jarvis, Ian; Kelly, Mary H; Julius; Gillmore, Gavin
Subject:	Re: Outcome Email: 1819 074.1 The Socio-Economic and Environmental Implications of Shale Gas Development in the Karoo, South Africa

Dear Julius
Thank you for your attention to the feedback from the ethics committee.
I am happy to approve this application by Chair's Action.

However, I have a couple of comments about your implementation of some of the guidance.
Current GDPR best practice is to give a clear time indication on retention. You say that data will be destroyed after transcription but obviously the transcribed data will be retained for much longer. It would be worth adding 'the merged and transcribed results will be retained for the duration of this project and subsequent publication'.

The nature of your questions in the questionnaire is fine from an ethical standpoint, but I recommend you add 'prefer not to say' and also 'other' to your questions on both political and cultural affiliation questions. Sometimes people feel anxious disclosing these aspects but would be happy to answer the rest of the survey. Also some people may not feel the options you present exactly reflect their affiliations and this may cause them discomfort on how to answer. I am happy for you to discuss this with your supervisorial team and make a decision - we do not need to see further documentation.

Best wishes,
Layla

Appendix 2: Application Form for Ethical Review Re4

(For Research Involving Human Participants)

SECTION A

Is this an application for a 'block release agreement'?	Yes		No	x

If *yes*, please specify the name of the group/cohort and note who will be responsible for ethical oversight of projects in this area (the block release holder); this will usually be the module leader, supervisor or head of subject. This RE4 form should present a project *typical* to this group/cohort.

N/A

Project title:

The Environmental and Socio-Economic Implications of Shale Gas Development in the Karoo, South Africa

Name of the lead applicant:

Name (Title / first name / surname):	Julius Irene
Positedion held:	PhD Student
Department/School/Faculty:	Faculty of Science, Engineering and Computing
Telephone:	+447368372900
Email address:	j2bridge@yahoo.com; k1737982@kingston.ac.uk

Is the project:					
	Student research	Yes	x	No	
	KU Staff research	Yes		No	x
	Research on KU premises	Yes		No	x

If it is STUDENT research:

Course title	PhD Research
Supervisor/DoS	Supervisors: Prof Ian Jarvis and Dr Mary Kelly DoS: Prof Gavin Gilmore

SECTION B ***(Complete this section if another ethics committee has already granted approval for the project. Otherwise, proceed to Section C)***

Committee that granted approval	
Date of approval	

Please attach evidence that the project has been fully approved (usually an approval letter). The original application should be retained on file in the Faculty for inspection where necessary. The Faculty Research Ethics Committee (FREC) may require further information or clarification from you and you should not embark on the project until you receive notification from the FREC that recognition of the approval has been granted. You should proceed directly to Section D of this form and submit this as a fast-track application.

SECTION C

Provide a brief project description (max. 150 words). This should be written for a lay audience

Shale Gas Development has revolutionized the global energy landscape, especially in the United States. Rapid Shale gas development has also caused significant public concerns on human health and the environment at the community and global level.

In the broadest sense, the divergent views and public perception of developing the Shale gas industry in South Africa are shrouded in uncertainty thereby rendering cost-benefit estimates very difficult.

This study provides an in-depth evidence-based analysis of the impact of ‘’fracking’’ the Karoo and provide a better understanding of the benefits and challenges in the short and long term for effective decision making.

Estimate duration of the project (months)	2 Months

State the source of funding	Self-Funded

Is it collaborative research?	Yes		No	x

If YES, name of the collaborator institutions:

1.	
2.	

Briefly describe the procedures to be used which involve human participants.

Broadly, this study uses a mixed method research approach to answer the research questions. The mixed methods research extends the existing body of literature concerning the impact studies and the analysis of the public perception of Shale gas development in South Africa.

Realizing that a quantitative approach alone can miss nuanced parts of this inquiry, the research approach will rely on semi-structured interviews utilizing open-ended questions to probe deeper into public perception concerning Shale gas development in the Karoo and to supplement a robust statistical analysis that can be generalized to a larger population.

In a broad sense, this research involves standard research practice using interviews, questionnaire/ surveys, and public observations. The research will focus on maintaining confidentiality and informed consent of participants and also ensure the selection of participants is equitable. The researcher will ensure participation is voluntary and participants are able to withdraw from the study at any time.

The interviews will be face to face and tape recorded. All audio recordings will be deleted after the transcription of the data.

Furthermore, the researcher will ensure the participant fully understand what they are being asked to do in order to make a reasoned judgment about the effect of participation. The researcher will provide full disclosure about the nature of the study, the risks, benefits, and alternatives, and provide an extended opportunity to ask questions before deciding whether or not to participate. On the contrary, the researcher will diminish the participation from the vulnerable population (for example, children, cognitively impaired elderly, or mentally ill subjects).

This research does not involve collaboration with any organisation in South Africa.

Summarise the data sources to be used in the project

Qualitative Data Sources

The main methods for collecting qualitative data will involve individual interviews or observations and direct interaction with individuals in a group setting.

Participants for the qualitative research will involve a variety of respondents (e.g., experts, regulators, districts heads, local residents etc) to draw from a different perspective in order to provide a rich outcome.

The sampling size for the qualitative research will be small compared to the quantitative aspect of the study based on the time that will be spent interviewing respondents and financial constraint.

Respondents will be selected using the snowballing method.

Quantitative Data Sources
The source of quantitative data is a survey and open-ended questionnaires with carefully constructed questions ranking or scoring options. The range of questions is designed to provide a snapshot of perception or behavior regarding Shale gas development in the Karoo. Sampling will be random method aimed to achieve representative of the population and a degree of acceptable accuracy.

Given that the respondents are in different regions in South Africa and the cost of reaching them will be high, questionnaires will be disseminated via email, online survey (SurveyMonkey and MS Office forms) and face to face. Access to the respondents will be via personal contact and professional networks (i.e. The South African Council for Natural Scientific Professions (SACNASP) and The Council for Geoscience (CGS).

Given the research design and research aims and objectives, the sample will be purposively selected using predetermined inclusion criteria (for the qualitative aspect of this research). For the quantification study samples will be drawn by simple random selection from the population.

Storage, access, and disposal of data

Describe what research data will be stored, where, for what period of time, the measures that will be put in place to ensure the security of the data, who will have access to the data, and the method and timing of disposal of the data.

Data will be collected anonymously with no reference to the personal information of the participant. Data will be stored confidentially for a number of years after the study has finished [OR] as long as it is necessary to verify and defend when required, the process and outcomes of the research. The time period may be a number of years.

Initially, data will be stored on an encrypted storage device then transferred to the University's networked fileservers for safe keeping.

To avoid corruption and loss of data, this researcher will ensure data is regularly backed up in Kingston University Box storage to safeguard the data and retrievable should the original gets lost or corrupted. Please note the University Box storage is GDPR compliant.

Non-digital textual data will ideally be digitized to facilitate long-term preservation and sharing.

FYI: (The university Box storage is GDPR compliant).

Risk Assessment Questionnaire: Does the proposed research involve any of the following?

	YES	NO
The use of human biological material?		X
Children or young people under 18 years of age?		X
If YES, have you complied with the requirements of the DBS?		X
People with intellectual or mental impairment, temporary or permanent?		X
People highly dependent on medical care, e.g., emergency care, intensive care, neonatal intensive care, terminally ill, or unconscious?		X
Prisoners, illegal immigrants or financially destitute?		X
Women who are known to be pregnant?		X
Will people from a specific ethnic, cultural or indigenous group be targeted in the proposed research, or is there potential that they may be targeted?		X
Assisted reproductive technology?		X
Human genetic research?		X
Epidemiology research?		X
Stem cell research?		X
Use of environmentally toxic chemicals?		X
Use of ionizing radiation?		X
Ingestion of potentially harmful or harmful dose of foods, fluids or drugs?		X
Contravention of social/cultural boundaries?		X
Involves use of data without prior consent?		X
Involves bodily contact?		X
Compromising professional boundaries between participants and researchers?		X
Deception of participants, concealment or covert observation?		X
Will this research significantly affect the health* outcomes or health services of subjects or communities?		X
Is there a significant risk of enduring physical and/or psychological		X

harm/distress to participants?		
Does your research raise any issues of personal safety for you or other researchers involved? (especially if taking place outside working hours or off KU premises)		X
Will the research be conducted without written informed consent being obtained from the participants except where tacit consent is given by completing a questionnaire?		X
Will financial/in kind payments (other than reasonable expenses and compensation for time) be offered to participants? (Indicate in the proposal how much and on what basis)		X
Is there a potential danger to participants in case of accidental unauthorised access to data?		X

[**Note** *health is defined as not just the physical well-being of the individual but also the social, emotional, and cultural well-being of the whole community].

<u>SECTION D</u> ***(To be signed by all applicants)***

Declaration to be signed by the applicant(s) and the supervisor (in the case of a student):

- I confirm that the research will be undertaken in accordance with the Kingston University *Guidance and procedures for undertaking research involving human participants.*

- I will undertake to report formally to the relevant Faculty Research Ethics Committee for continuing review approval where required.

- I shall ensure that any changes in approved research protocols or membership of the research team are reported promptly for approval by the relevant Faculty Research Ethics Committee.

- I shall ensure that the research study complies with the law and University policy on Health and Safety.

- I confirm that the research study is compliant with the requirements of the Disclosure and Barring Service where applicable.

- I am satisfied that the research study is compliant with the Data Protection Act 1998, and that necessary arrangements have been, or will be made with regard to the storage and processing of participants' personal information and generally, to ensure confidentiality of such data supplied and generated in the course of the research.
  (Further advice may be sought from the Data Protection Officer, University Secretary's Office)
- I shall ensure that the research is undertaken in accordance with the University's Single Equality Scheme.

- I will ensure that all adverse or unforeseen problems arising from the research project are reported immediately to the Chair of the relevant Faculty Research Ethics Committee.

- I will undertake to provide notification when the study is complete and if it fails to start or is abandoned.

- (For supervisors, *if the applicant is a student)* I have met and advised the student on the ethical aspects of the study design and am satisfied that it complies with the current professional (*where relevant),* departmental and University guidelines. I accept responsibility for the conduct of this research and the maintenance of any consent documents as required by this Committee.

- I understand that failure to provide accurate information can invalidate ethical approval.

Is this an application for fast-track ethical approval? (Fast track is **only** available for projects either pre-approved by another ethics committee or where you have accurately indicated 'No' to every question on the Risk Assessment Questionnaire – Pg4)	**Yes**	x	**No**	

Please sign and date

	Signature	*Date*
Lead applicant		11/05/2019

NOTE

If this is a block release application and/or you have answered YES to any of the questions in the Risk Assessment, you must complete a full application for ethical approval and provide the information outlined in the checklist below. Your project proposal should show that there are adequate controls in place to address the issues raised in your Risk Assessment.

If you have answered NO to all of the questions in the Risk Assessment you may submit the form to your Faculty Ethics Administrator as a fast-track application. You must append your participant information sheet. The Faculty Research Ethics Committee (FREC) may require further information or clarification from you and you should not embark on the project until you receive notification from your Faculty that recognition of the approval has been granted.

CHECKLIST ***(Where a full application for ethical approval is required)***

Please complete the checklist and attach it to your full application for ethical approval:

Before submitting this application, please check that you have done the following: *(N/A = not applicable)*	**Applicant**			*Committee use only*		
	Yes	**No**	**N/A**	**Yes**	**No**	**N/A**
All questions have been answered	**x**					
All applicants have signed the application form	**x**					
The research proposal is attached	**x**					
Informed Consent Form is attached	**x**					
Participant Information Sheets are attached	**x**					
All letters, advertisements, posters or other recruitment material to be used are attached	**x**					
All surveys, questionnaires, interview/focus group schedules, data sheets, etc, to be used in collecting data are attached	**x**					
Reference list attached, where applicable	**x**					

Appendix 3: Qualitative Instrument – Interview

The Environmental and Socio-Economic Impact of Shale Gas Development in the Karoo, South Africa

Part A: Sociodemographic Information

Gender

Male ☐ Female ☐

Age

18-30 ☐ 31-40 ☐ 41-50 ☐ 51-60 ☐ > 60 ☐

Occupation

Geologist ☐ Academics ☐ NGO/Environmentalist ☐ Council/Community Head ☐

Politician ☐ Religious Leader ☐ Business ☐ Retail ☐ Farmer ☐

Travel/Tourism ☐ Finance ☐ Construction/Maintenance ☐

If occupation not listed, please specify your occupation here ☐

Perception

1. Do you consider shale gas development potentially harmful to the environment? Please explain.

2. What do you consider as the main risk about fracking or Shale gas development? Please explain.

3. What do you consider as the main benefits about fracking or Shale gas development? Please explain.

4. Is your perception concerning shale gas development likely to change in the future? Please explain.

Public Access to Information

5. What do you consider as the credible source of information on shale gas development? Please explain.

Stakeholder Engagement and Participation

6. Do you approve/ support the central government / oil companies (public) engagement strategy and social representation concerning shale gas development in the Karoo? Please explain.

Policy

7. Are you in support of fracking /Shale gas development in the Karoo? Please explain.

8. Do you support the current temporary ban on fracking in South Africa? Please explain.

9. What is your level of institutional trust and governance of shale gas development? Please explain.

10. Is shale gas the optimal transition energy to a sustainable energy future? Please explain.

11. Do you agree that South Africa will have a shale boom? Please explain.

Karoo-Specific

12. What do you consider as the main impact of Shale gas development in the Karoo Community? Please explain.

13. What would the economic effect be of a complete ban of fracking in the Karoo? Please explain.

14. Will a change in land rights where landowners own and control the resources on their land change your perception about Shale gas development? Please explain.

15. Do you believe that fracking or Shale gas development will occur in South Africa? Please explain.

16. What is the impact of shale gas development on the Karoo ecological system? Please explain.

17. What do you consider that the potential benefits outweigh the risks of shale gas development? Please explain.

Thank you for your time.

Appendix 4: Quantitative Instrument - Survey Questionnaire

Part A Sociodemographic Information

*Please tick one box for each item only.

1.YOUR CURRENT AGE						
Under 18	18- 30	31-40	41-50	41-50	51-60	61 or above

2. MARITAL STATUS					
Single	Married	Civil partner	Widowed	Divorced	N/A

3. GENDER	
Male	Female

4. OCCUPATION						
Farmer	Tourism / Real Estate	Government Employee	Business / Retail / Finance	Construction/ Maintenance	Technical/ Engineering/ Academics	NGO's Others (Please specify)

5. INCOME				
Below R12,000 p/a	R12,001 to R150,000	R150,001 to R1,000,000	R1,000,001 to R5,000,000	Above R5,000,000

6. EDUCATIONAL QUALIFICATION						
Below Matric	Matric	National Diploma	Bachelor's Degree	Post Graduate Degree	No Formal Education	Don't know / Prefer not to say

7. CULTURAL ORIENTATION

Black	White	Indian	Coloured

8.POLITICAL AFFILIATION

☐African Christian Democratic Party ☐African Independent Congress ☐ African National Congress ☐African Peoples' Convention ☐Agang South Africa ☐Congress of the People ☐Democratic Alliance ☐Economic Freedom Fighters ☐Freedom Front Plus ☐Inkatha Freedom Party ☐National Freedom Party ☐Pan Africanist Congress ☐United Democratic Movement ☐ N/A

To what extent do you agree or disagree with the following statements about your experience

Strongly Opposed	Somewhat Opposed	Neutral	Somewhat in Favour	Strongly in Favour
1	2	3	4	5

9. PERCEPTION					
Please choose from the above legend	1	2	3	4	5
Fracking will reduce South Africa dependency on foreign sources of energy					
Fracking will reduce the South Africa carbon footprint					
Fracking will reduce gas prices for energy companies					
Fracking will reduce my energy bills					
Fracking will be safe if it is regulated and monitored properly					
Fracking will create new jobs					
Fracking will boost economic growth					
It’s possible to compensate for the risks of fracking by payments to local communities					
Fracking will provide South Africa with a secure energy source for decades					
Fracking will have no effect on reducing energy bills					
Fracking will damage the local environment					
Fracking could cause earthquakes and tremors					
Fracking could impact agriculture and tourism					
Fracking could contaminate local water sources					
There is no effective way to regulate fracking to make it safe in South Africa					
Fracking will keep South Africa tied to using fossil fuels, which contribute to climate change					
Government of South Africa should invest in renewable energy instead					
Improved relationships between community members					
Increased economic equality in communities					

More tax revenue					
Economic Benefits for Local Communities					
More money for the state budget					
Financial benefits for landowners					
Financial benefits for gas companies					
Reduced access to public land					
Harm to wild animals and plants					
Shale gas as transition energy					
A shift from coal to Shale gas would benefit public health and environment					
A shift from Nuclear energy to Shale gas would benefit public health					

Strongly Opposed	Somewhat Opposed	Neutral	Somewhat in Favour	Strongly in Favour
1	2	3	4	5

10. RISKS AND BENEFITS

Please choose from the above legend	1	2	3	4	5
Reduce access to private land					
Light disturbances					
Risks to livestock					
Crop damage					
Air pollution					
Odour related problems					
Noise disturbances					
Increase property value					
Damage to the Environmental aesthetics					
Health risks					

11. What is your major concern regarding Shale gas development (‘select all that apply’).

☐ Water contamination ☐ Air contamination ☐ Human and animal health ☐ Threats to existing economies (agriculture, tourism) ☐ Surface disruption ☐ Water usage / shortage ☐ Increase in violence and crime ☐ Loss of landscape/sense of place ☐ Waste overflow ☐ Displacement ☐ Earthquake /Tremors ☐ Global warming ☐ Loss of landscape/aesthetic degradation ☐ N/A please specify

12.The potential benefits of Shale gas (‘select all that apply’).

☐ Potential work opportunities ☐ Lowering CO2 emissions ☐ Affordable ☐ Economic growth ☐ Shale gas is an alternative energy ☐ Reinvestment into the Community ☐ N/A please specify

To what extent do you agree or disagree with the following statements about your experience

Strongly Opposed	Somewhat Opposed	Neutral	Somewhat in Favour	Strongly in Favour
1	2	3	4	5

13. SOCIAL ISSUES (Impact on the Community)					
Please choose from the above legend	1	2	3	4	5
Influx of immigrants					
Increase in cost of living					
Competition for local businesses					
Increases in crime					
Unfair gas leases to gas companies					
Famine and shortage of water					
Increased community economic inequality					
Strain on sewer / municipality facilities					
Land capture by government					
Strain on community cohesion / place disruption					

For each of the following statements, please indicate your experience.

AWARENESS	
14. I turn to the following for information on fracking	Tick
Television or radio news	
Local newspaper(s)	
People I know personally (e.g., friends, family, colleagues)	
Non-news websites containing information/arguments against fracking	
Environmental/anti-fracking groups via leaflets, newsletters, films or events	
Non-news websites containing information/arguments in favour of fracking	
People I know personally (e.g., friends, family, colleagues)	
Social media (e.g., Twitter, Facebook)	
Books, magazines or scientific journals	
National South Africa newspaper(s) (print or online editions)	
Unsure/none of these	

15. Now please tell me which of the following statements comes closest to your views concerning expert view on hydraulic fracking:	Tick
Most experts agree that the risks associated with hydraulic fracking are HIGH	
Most experts agree that the risks associated with hydraulic fracking are LOW	
Most experts are divided on whether hydraulic fracking poses any risk	
Earthquakes	
Land Destruction/Fragmentation	
Health Issues	
Safety Issues/Well Integrity / Dangers	
Economic Growth	
Job Creation	

Other (please specify)	

16. How much, if anything, do you know about fracking or Shale gas development

A Lot	A Fair Amount	Not Sure	Not at All

To what extent do you agree or disagree with the following statements about your experience

17. ATTITUDE / GOVERNANCE

15. Are you in support of fracking / Shale gas development in the Karoo

Strongly Opposed	Somewhat Opposed	Neutral	Somewhat in Favour	Strongly in Favour

18. I support the current temporary ban on fracking in South Africa

Strongly Agree	Somewhat Agree	Neutral	Somewhat Disagree	Strongly Disagree

19. I approve government / oil companies (public) engagement strategy concerning fracking

Strongly Agree	Somewhat Agree	Neutral	Somewhat Disagree	Strongly Disagree

20. I support stringent regulation on fracking in South Africa

Strongly Agree	Somewhat Agree	Neutral	Somewhat Disagree	Strongly Disagree

21. More research is needed on fracking to better understand potential risks.

Strongly Agree	Somewhat Agree	Neutral	Somewhat Disagree	Strongly Disagree

22. What is your preferred energy source?

Coal	Nuclear	Solar	Natural Gas	Offshore wind

THE FUTURE

22. Fracking need to be more regulated to protect human health and the environment.

Very Likely	Somewhat Likely	Neutral	Somewhat Unlikely	Very Unlikely

23. Living in an area licensed for shale gas development

Very Likely	Somewhat Likely	Neutral	Somewhat Unlikely	Very Unlikely

THIS SURVEY ENDS HERE.

THANK YOU VERY MUCH FOR YOUR COOPERATION.

Appendix 5: Informed Consent for Participation in the following Research Project

The Socio-Economic and Environmental Implications of Shale Gas Development in the Karoo, South Africa.

Please tick the appropriate boxes **Yes** **No**

1. **Taking part in the study**

I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction. ☐ ☐

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason. ☐ ☐

2. **Use of the information in the study**

I understand that information I provide will be used for **research purpose** ☐ ☐

I understand that personal information collected about me that can identify me, such as my name or where I live, will not be shared beyond the study team and will be safe guarded. ☐ ☐

I agree that the information I provide can be quoted in research outputs. ☐ ☐

3. **Future use and reuse of the information by others**

I give permission for the information, including audio recordings and survey data that I provide to be depositeded anonymously in **Kingston** University Box storage so it can be used for future research and learning. ☐ ☐

4. **Signatures**

___________________________ _______________________ _____________

Name of participant [IN CAPITALS] Signature Date

For participants unable to sign their name, mark the box instead of signing. ☐

I have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Name of witness [IN CAPITALS] Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Name of researcher [IN CAPITALS] Signature Date

5. **Study contact details for further information**

David Macintosh, Dean, Faculty of Science, Engineering and Computing, Kingston University, Penrhyn Road, Kingston upon Thames, Surrey KT1 2EE d.macintosh@kingston.ac.uk

Appendix 6: Information for Participants

Research: Environmental and The Socio-Economic Implications of Shale Gas Development in the Karoo, South Africa.

The Research: There is growing recognition of the need to understand public attitudes to energy sources, such as Shale gas, and to feed these into decision-making. This study represents an investigation and survey of public perceptions of Shale gas fracking, including analysis of the effects of different messages and the relative influence of different audience, message and contextual factors on support and risk perceptions in respect of Shale gas fracking in the Karoo, South Africa.

This is a PhD research project from the Department of Geography, Geology and the Environment. This study has been approved by Kingston University (KU) Departmental Ethics Screening Committee and will be conducted according to accepted and applicable KU ethics guidelines and principles. The survey is anonymous and response data will only be analyzed at aggregate level.

The project is voluntary and, up to the point of analysis, you can withdraw your reflection, at any time by contacting the researcher (Julius Irene). As such you can have your input removed from the project.

All data will be held confidentially in accordance with the requirements of the Data Protection Act. It will only be viewed and accessed by a limited group of people for the purposes of this research. The merged and transcribed results will be retained for the duration of this project and subsequent publication. At all times Kingston University will abide by its Data Protection Policy, which can be found here https://www.kingston.ac.uk/privacy-policy/.

At no point will the information you provide be shared in a way that would allow you to be personally identified. Any published material will be anonymized. You have the right to request access to your personal data that we hold, to have your personal data amend-ed/corrected, and/or to have your personal data deleted.

The study results can be sent to you should you wish.

The study results may be disseminated at academic conferences, through published reports and or academic papers.

PhD Researcher:

Julius Irene +447368372900 k1737982@kingston.ac.uk

Appendix 7: Mean Ranks

	Ethnic Groups	N	Mean Rank
Fracking will reduce South Africa dependency on foreign sources of energy	Black	49	134.64
	White	82	104.28
	Indian	38	167.53
	Coloured	92	137.79
	Total	261	
Fracking will reduce South Africa carbon footprint	Black	49	147.09
	White	82	91.14
	Indian	38	180.79
	Coloured	92	137.39
	Total	261	
Fracking will reduce gas prices for energy/big companies in South Africa	Black	49	121.70
	White	82	71.88
	Indian	38	191.37
	Coloured	92	163.71
	Total	261	
Fracking will reduce my energy cost	Black	49	136.49
	White	82	72.38
	Indian	38	162.32
	Coloured	92	167.39
	Total	261	
Fracking will be safe if it is regulated and monitored properly	Black	49	125.66
	White	82	65.98
	Indian	38	175.71
	Coloured	92	173.33
	Total	261	
Fracking will create new jobs	Black	49	149.90
	White	82	95.91
	Indian	38	176.03
	Coloured	92	133.61
	Total	261	
Fracking will boost economic growth	Black	49	143.72
	White	82	74.01
	Indian	38	179.39
	Coloured	92	155.03
	Total	261	
CSR activities in the local communities will reduce the risk of fracking	Black	49	128.10
	White	82	89.61
	Indian	38	131.68
	Coloured	92	169.15
	Total	261	
Fracking will provide South Africa with a secure energy source for decades	Black	49	163.42
	White	82	101.83

	Indian	38	143.99
	Coloured	92	134.37
	Total	261	
Fracking will have no effect on reducing energy bills	Black	49	63.85
	White	82	98.80
	Indian	38	193.55
	Coloured	92	169.63
	Total	261	
Fracking will damage the local environment	Black	49	92.01
	White	82	91.12
	Indian	38	162.43
	Coloured	92	174.33
	Total	261	
Fracking will cause earthquakes and tremors	Black	49	104.54
	White	82	79.74
	Indian	38	169.14
	Coloured	92	175.02
	Total	261	
Fracking will impact agriculture and tourism	Black	49	98.16
	White	82	101.85
	Indian	38	150.47
	Coloured	92	166.42
	Total	261	
Fracking will contaminate the local source of domestic water	Black	49	109.42
	White	82	126.98
	Indian	38	138.89
	Coloured	92	142.82
	Total	261	
There is no effective way to regulate fracking to make it safe in South Africa	Black	49	133.02
	White	82	137.09
	Indian	38	131.14
	Coloured	92	124.43
	Total	261	
Fracking will keep South Africa tied to using fossil fuels, which contribute to climate change	Black	49	140.76
	White	82	146.57
	Indian	38	142.01
	Coloured	92	107.38
	Total	261	
Government of South Africa should rather invest in renewable / green energy	Black	49	117.80
	White	82	133.40
	Indian	38	156.82
	Coloured	92	125.23
	Total	261	
Fracking will Improve relationships between neighboring community and reduce conflicts	Black	49	204.51
	White	82	123.90
	Indian	38	122.96
	Coloured	92	101.49

	Total	261	
Increased economic equality within the community	Black	49	140.41
	White	82	61.27
	Indian	38	172.29
	Coloured	92	171.09
	Total	261	
Shale gas development will provide government with more tax revenue	Black	49	111.41
	White	82	109.30
	Indian	38	138.50
	Coloured	92	157.67
	Total	261	
Shale gas development will boost manufacturing industries	Black	49	140.19
	White	82	92.47
	Indian	38	150.67
	Coloured	92	152.32
	Total	261	
Fracking will enhance the GDP of the municipality and attract foreign investors	Black	49	127.61
	White	82	109.59
	Indian	38	134.09
	Coloured	92	150.61
	Total	261	
Shale gas development will enhance financial benefits for landowners	Black	49	167.73
	White	82	111.18
	Indian	38	147.33
	Coloured	92	122.36
	Total	261	
Financial benefits for gas companies	Black	49	85.32
	White	82	113.87
	Indian	38	134.01
	Coloured	92	169.36
	Total	261	
Reduced access to public land	Black	49	150.15
	White	82	177.38
	Indian	38	118.96
	Coloured	92	84.43
	Total	261	
Harm to wildlife and plants (Ecosystem)	Black	49	101.55
	White	82	120.46
	Indian	38	155.67
	Coloured	92	145.89
	Total	261	
Shale gas as transition energy	Black	49	191.85
	White	82	162.11
	Indian	38	92.91
	Coloured	92	86.60
	Total	261	
A shift from coal to shale gas would benefit public	Black	49	151.44

health and environment	White	82	103.51
	Indian	38	162.00
	Coloured	92	131.82
	Total	261	
A shift from nuclear energy to shale gas would benefit public health	Black	49	142.53
	White	82	96.55
	Indian	38	150.74
	Coloured	92	147.41
	Total	261	
Reduce access to private land / land capture by government	Black	49	114.59
	White	82	156.38
	Indian	38	153.93
	Coloured	92	107.65
	Total	261	
Fracking will result in light pollution	Black	49	127.07
	White	82	108.39
	Indian	38	143.47
	Coloured	92	148.09
	Total	261	
Fracking will impact air quality	Black	49	146.31
	White	82	137.82
	Indian	38	139.46
	Coloured	92	113.27
	Total	261	
Fracking will result in noise pollution	Black	49	128.55
	White	82	142.79
	Indian	38	162.54
	Coloured	92	108.77
	Total	261	
Shale gas development will increase property / housing value	Black	49	156.41
	White	82	130.94
	Indian	38	150.21
	Coloured	92	109.59
	Total	261	
Water contamination and related Issues	Black	49	156.31
	White	82	114.63
	Indian	38	155.26
	Coloured	92	122.09
	Total	261	
Fracking will Impact human health	Black	49	146.41
	White	82	145.52
	Indian	38	140.58
	Coloured	92	105.89
	Total	261	
What are your major concerns/ risks regarding shale gas development	Black	49	113.82
	White	82	82.55
	Indian	38	153.71

	Coloured	92	173.96
	Total	261	
Potential benefits regarding shale gas development	Black	49	143.36
	White	82	85.25
	Indian	38	140.89
	Coloured	92	161.11
	Total	261	
Shale gas development will trigger increase in migrant workers	Black	49	142.53
	White	82	150.59
	Indian	38	111.45
	Coloured	92	115.47
	Total	261	
Shale gas development will trigger increase in cost of living	Black	49	152.12
	White	82	170.96
	Indian	38	110.55
	Coloured	92	92.58
	Total	261	
Shale gas development will trigger competition for local businesses	Black	49	154.64
	White	82	166.70
	Indian	38	156.71
	Coloured	92	75.97
	Total	261	
Shale gas development will drive the increase of crime	Black	49	152.96
	White	82	161.46
	Indian	38	113.34
	Coloured	92	99.45
	Total	261	
Unfair gas exploration leases to oil and gas companies	Black	49	141.85
	White	82	126.99
	Indian	38	138.88
	Coloured	92	125.54
	Total	261	
Shale gas development will cause famine and shortage of water	Black	49	105.92
	White	82	122.74
	Indian	38	145.39
	Coloured	92	145.77
	Total	261	
Increase in community economic inequality	Black	49	159.16
	White	82	188.85
	Indian	38	94.24
	Coloured	92	79.63
	Total	261	
Strain on social / municipality facilities	Black	49	131.13
	White	82	168.85
	Indian	38	143.42
	Coloured	92	92.07
	Total	261	

Fracking will encourage land grab / capture by government	Black	49	112.45
	White	82	153.60
	Indian	38	127.53
	Coloured	92	122.17
	Total	261	
Strain on community cohesion / place disruption	Black	49	170.87
	White	82	179.76
	Indian	38	92.05
	Coloured	92	82.40
	Total	261	
I turn to the following source for information on fracking	Black	49	145.30
	White	82	168.87
	Indian	38	105.09
	Coloured	92	100.33
	Total	261	
What is expert view on hydraulic fracking / shale gas development	Black	49	180.15
	White	82	65.05
	Indian	38	171.99
	Coloured	92	146.67
	Total	261	
How much do you know about fracking or shale gas development	Black	49	129.50
	White	82	135.50
	Indian	38	106.21
	Coloured	92	138.03
	Total	261	
Are you in support of fracking / shale gas development in the Karoo	Black	49	189.95
	White	82	62.77
	Indian	38	71.13
	Coloured	92	185.14
	Total	261	
I support the current temporary ban on fracking in South Africa	Black	49	156.85
	White	82	66.25
	Indian	38	92.32
	Coloured	92	190.92
	Total	261	
I approve government / oil companies (public) engagement strategy concerning fracking	Black	49	144.12
	White	82	175.43
	Indian	38	95.97
	Coloured	92	98.88
	Total	261	
I support stringent regulation on fracking in South Africa	Black	49	112.20
	White	82	86.49
	Indian	38	150.32
	Coloured	92	172.71
	Total	261	
More research is needed on fracking to better understand potential risks and benefits	Black	49	120.96
	White	82	99.82

	Indian	38	122.88
	Coloured	92	167.49
	Total	261	
What is your preferred energy source	Black	49	108.40
	White	82	157.81
	Indian	38	156.76
	Coloured	92	108.50
	Total	261	
Likelihood of fracking operations to be properly regulated in South Africa	Black	49	95.73
	White	82	148.24
	Indian	38	119.64
	Coloured	92	139.10
	Total	261	
Fracking will occur in or near my neighborhood	Black	49	94.88
	White	82	160.79
	Indian	38	125.25
	Coloured	92	126.07
	Total	261	

Appendix 8: Test Statistics for Hypothesis

Test Statisticsa

	Fracking will reduce South Africa dependency on foreign sources of energy	Fracking will reduce South Africa carbon footprint*	Fracking will reduce gas prices for energy/big companies in South Africa*
N	261	261	261
Median	3.0000	3.000	4.0000
Chi-Square	15.530[b]	46.397[c]	27.442[d]
df	3	3	3
Asymp. Sig.	.000	.000	.000

Test Statistics[a]

	Fracking will reduce my energy cost*	Fracking will be safe if it is regulated and monitored properly*	Fracking will create new jobs*
N	261	261	261
Median	3.0000	3.000	4.0000
Chi-Square	64.245[e]	89.061[f]	19.473[g]
df	3	3	3
Asymp. Sig.	.000	.000	.000

Test Statistics[a]

	Fracking will boost economic growth*	CSR activities in the local communities will reduce the risk of fracking*	Fracking will provide South Africa with a secure energy source for decades*
N	261	261	261
Median	4.0000	4.0000	2.0000
Chi-Square	25.401[h]	22.944[i]	26.027[j]
df	3	3	3
Asymp. Sig.	.000	.000	.000

Test Statistics[a]

	Fracking will have no effect on reducing energy bills*	Fracking will damage the local environment	Fracking will cause earthquakes and tremors*
N	261	261	261
Median	2.0000	4.0000	4.0000

Chi-Square	80.021[k]	32.534[l]	36.390[m]
df	3	3	3
Asymp. Sig.	.000	.000	.000

Test Statistics[a]

	Fracking will impact agriculture and tourism	Fracking will contaminate the local source of domestic water	There is no effective way to regulate fracking to make it safe in South Africa
N	261	261	261
Median	4.0000	4.0000	2.0000
Chi-Square	22.938[n]	1.132[o]	.491[p]
df	3	3	3
Asymp. Sig.	.000	.769	.921

Test Statistics[a]

	Fracking will keep South Africa tied to using fossil fuels, which contribute to climate change	Government of South Africa should rather invest in renewable / green energy	Fracking will Improve relationships between neighboring community and reduce conflicts*
N	261	261	261
Median	3.0000	4.0000	2.0000
Chi-Square	16.030[q]	4.997[r]	91.477[s]
df	3	3	3
Asymp. Sig.	.001	.172	.000

Test Statistics[a]

	Increased economic equality within the community*	Shale gas development will provide government with more tax revenue	Shale gas development will boost manufacturing industries*
N	261	261	261
Median	4.0000	4.0000	4.0000
Chi-Square	16.236[t]	17.035[u]	11.252[r]
df	3	3	3
Asymp. Sig.	.001	.001	.010

Test Statistics[a]

	Fracking will enhance the GDP of the municipality and attract foreign investors	Shale gas development will enhance financial benefits for landowners*	Financial benefits for gas companies
N	261	261	261
Median	4.0000	2.0000	4.0000
Chi-Square	3.697[v]	23.040[w]	33.903[k]
df	3	3	3
Asymp. Sig.	.296	.000	.000

Test Statistics[a]

	Reduced access to public land	Harm to wildlife and plants (Ecosystem)	Shale gas as transition energy*
N	261	261	261
Median	3.0000	4.0000	2.0000
Chi-Square	86.609[x]	8.709[y]	74.989[z]
df	3	3	3
Asymp. Sig.	.000	.033	.000

Test Statistics[a]

	A shift from coal to shale gas would benefit public health and environment*	A shift from nuclear energy to shale gas would benefit public health*	Reduce access to private land / land capture by government
N	261	261	261
Median	3.0000	4.0000	4.0000
Chi-Square	18.746[aa]	14.649[ab]	16.302[ac]
df	3	3	3
Asymp. Sig.	.000	.002	.001

Test Statistics[a]

	Fracking will result in light pollution	Fracking will impact air quality	Fracking will result in noise pollution

N	261	261	261
Median	4.0000	4.0000	4.0000
Chi-Square	4.678[ad]	4.747[s]	18.026[ae]
df	3	3	3
Asymp. Sig.	.197	.191	.000

Test Statistics[a]

	Shale gas development will increase property / housing value	Water contamination and related Issues	Fracking will Impact human health
N	261	261	261
Median	4.0000	4.0000	4.0000
Chi-Square	8.738[af]	11.178[ag]	9.155[af]
df	3	3	3
Asymp. Sig.	.033	.011	.027

Test Statistics[a]

	What are your major concerns/ risks regarding shale gas development	Potential benefits regarding shale gas development*	Shale gas development will trigger increase in migrant workers
N	261	261	261
Median	2.0000	3.0000	4.0000
Chi-Square	93.276[ah]	44.501[ai]	7.219[aj]
df	3	3	3
Asymp. Sig.	.000	.000	.065

Test Statistics[a]

	Shale gas development will trigger increase in cost of living	Shale gas development will trigger competition for local businesses	Shale gas development will drive the increase of crime
N	261	261	261
Median	3.0000	5.0000[ak]	3.0000
Chi-Square	44.790[p]		51.672[j]
df	3		3
Asymp. Sig.	.000		.000

Test Statistics[a]

	Unfair gas exploration leases to oil and gas companies	Shale gas development will cause famine and shortage of water	Increase in community economic inequality
N	261	261	261
Median	3.0000	4.0000	4.0000
Chi-Square	156.290[y]	25.118[ao]	6.525[ap]
df	3	3	3
Asymp. Sig.	.000	.000	.089

Test Statistics[a]

	Strain on social / municipality facilities	Fracking will encourage land grab / capture by government	Strain on community cohesion / place disruption
N	261	261	261
Median	4.0000	4.0000	3.0000
Chi-Square	25.118[ao]	6.525[ap]	95.193[aq]
df	3	3	3
Asymp. Sig.	.000	.089	.000

Test Statistics[a]

	I turn to the following source for information on fracking	What is expert view on hydraulic fracking / shale gas development*	How much do you know about fracking or shale gas development
N	261	261	261
Median	3.0000	2.0000	3.0000
Chi-Square	47.464[ar]	45.815[h]	3.752[as]
df	3	3	3
Asymp. Sig.	261	261	261

Test Statistics[a]

	Are you in support of fracking / shale gas development in the Karoo*	I support the current temporary ban on fracking in South Africa*	I approve government / oil companies (public) engagement strategy concerning fracking
N	261	261	261
Median	2.0000	3.0000	4.0000
Chi-Square	173.594[at]	65.812[n]	46.945[au]
df	3	3	3
Asymp. Sig.	.000	.000	.000

Test Statistics[a]

	I support stringent regulation on fracking in South Africa	More research is needed on fracking to better understand potential risks and benefits	What is your preferred energy source
N	261	261	261
Median	2.0000	2.0000	3.0000
Chi-Square	53.798[n]	50.863[z]	16.654[av]
df	3	3	3
Asymp. Sig.	.000	.000	.001

Test Statistics[a]

	Likelihood of fracking operations to be properly regulated in South Africa*	Fracking will occur in or near my neighbourhood*
N	261	261
Median	3.0000	4.0000
Chi-Square	9.881[aw]	17.535[aj]
df	3	3
Asymp. Sig.	.020	.001

a. Grouping Variable: Ethnic Groups
b. All values are less than or equal to the median. Median Test cannot be performed.

Appendix 9: Descriptive Summary

		N	Marginal Percentage
Are you in support of fracking/shale gas development in the Karoo	Strongly Opposed	99	37.9%
	Somewhat Opposed	47	18.0%
	Neutral	4	1.5%
	Somewhat in Support	75	28.7%
	Strongly in Support	36	13.8%
Age of Respondent	Between 18 and 30 years	65	24.9%
	Between 31 and 40 years	59	22.6%
	Between 41 and 50 years	73	28.0%
	Between 51 and 60 years	36	13.8%
	Between 61 and above	28	10.7%
Marital Status of Respondent	Single	62	23.8%
	Married	95	36.4%
	Civil	43	16.5%
	Widowed	42	16.1%
	Divorced	19	7.3%
Gender of Respondent	Male	136	52.1%
	Female	125	47.9%
Occupation of Respondent	Farmer	82	31.4%
	Tourism / Real Estate	38	14.6%
	Government Employee	43	16.5%
	Business / Retail	60	23.0%
	Construction / Maintenance	31	11.9%
	Technical / Engineering / Academics	6	2.3%
	NGO and Others	1	0.4%
Income of Respondent	Below R12,000	35	13.4%
	R12,001 to R150,000	116	44.4%
	R150,001 to R1,000,000	70	26.8%
	R1,000,001 to R5,000,000	26	10.0%
	above R5,000,000	14	5.4%
Education of Respondent	Below Matric	5	1.9%
	Matric	102	39.1%
	Bachelor's Degree	49	18.8%
	Post Graduate Degree	32	12.3%
	National Diploma / Trade Cert	73	28.0%
Ethnic Groups	Black	50	19.2%
	White	82	31.4%
	Indian	38	14.6%
	Colored	91	34.9%
Political Affiliation of Respondent	African Christian Democratic Party	40	15.3%

	African Independent Congress	11	4.2%
	African National Congress	32	12.3%
	African Peoples' Convention	31	11.9%
	Agang South Africa	28	10.7%
	Congress of the People	13	5.0%
	Democratic Alliance	100	38.3%
	Economic Freedom Fighters	2	0.8%
	National Freedom Party	4	1.5%
Fracking will reduce South Africa dependency on foreign sources of energy	Strongly Disagree	32	12.3%
	Somewhat Disagree	97	37.2%
	Neutral	49	18.8%
	Somewhat Agree	68	26.1%
	Strongly Agree	15	5.7%
Fracking will reduce the South Africa carbon footprint	Strongly Disagree	23	8.8%
	Somewhat Disagree	71	27.2%
	Neutral	68	26.1%
	Somewhat Agree	74	28.4%
	Strongly Agree	25	9.6%
Fracking will reduce gas prices for energy companies	Strongly Disagree	32	12.3%
	Somewhat Disagree	44	16.9%
	Neutral	42	16.1%
	Somewhat Agree	95	36.4%
	Strongly Agree	48	18.4%
Fracking will reduce my energy bills	Strongly Disagree	28	10.7%
	Somewhat Disagree	55	21.1%
	Neutral	48	18.4%
	Somewhat Agree	79	30.3%
	Strongly Agree	51	19.5%
Fracking will be safe if it is regulated and monitored properly	Strongly Disagree	34	13.0%
	Somewhat Disagree	59	22.6%
	Neutral	41	15.7%
	Somewhat Agree	79	30.3%
	Strongly Agree	48	18.4%
Fracking will create new jobs	Strongly Disagree	20	7.7%
	Somewhat Disagree	43	16.5%
	Neutral	67	25.7%
	Somewhat Agree	86	33.0%
	Strongly Agree	45	17.2%
Fracking will boost economic growth	Strongly Disagree	18	6.9%
	Somewhat Disagree	33	12.6%
	Neutral	50	19.2%
	Somewhat Agree	100	38.3%
	Strongly Agree	60	23.0%
It’s possible to compensate for the risks of fracking by payments to local communities	Strongly Disagree	43	16.5%
	Somewhat Disagree	89	34.1%
	Neutral	51	19.5%

	Somewhat Agree	57	21.8%
	Strongly Agree	21	8.0%
Fracking will provide South Africa with a secure energy source for decades	Strongly Disagree	73	28.0%
	Somewhat Disagree	78	29.9%
	Neutral	54	20.7%
	Somewhat Agree	42	16.1%
	Strongly Agree	14	5.4%
Fracking will have no effect on reducing energy bills	Strongly Disagree	62	23.8%
	Somewhat Disagree	131	50.2%
	Neutral	39	14.9%
	Somewhat Agree	19	7.3%
	Strongly Agree	10	3.8%
Fracking will damage the local environment	Strongly Disagree	89	34.1%
	Somewhat Disagree	77	29.5%
	Neutral	25	9.6%
	Somewhat Agree	51	19.5%
	Strongly Agree	19	7.3%
Fracking could cause earthquakes and tremors	Strongly Disagree	55	21.1%
	Somewhat Disagree	83	31.8%
	Neutral	68	26.1%
	Somewhat Agree	42	16.1%
	Strongly Agree	13	5.0%
Fracking could impact agriculture and tourism	Strongly Disagree	47	18.0%
	Somewhat Disagree	77	29.5%
	Neutral	42	16.1%
	Somewhat Agree	69	26.4%
	Strongly Agree	26	10.0%
Fracking could contaminate local water sources	Strongly Disagree	38	14.6%
	Somewhat Disagree	79	30.3%
	Neutral	45	17.2%
	Somewhat Agree	53	20.3%
	Strongly Agree	46	17.6%
There is no effective way to regulate fracking to make it safe in South Africa	Strongly Disagree	47	18.0%
	Somewhat Disagree	90	34.5%
	Neutral	45	17.2%
	Somewhat Agree	64	24.5%
	Strongly Agree	15	5.7%
Fracking will keep South Africa tied to using fossil fuels, which contribute to climate change	Strongly Disagree	9	3.4%
	Somewhat Disagree	37	14.2%
	Neutral	87	33.3%
	Somewhat Agree	84	32.2%
	Strongly Agree	44	16.9%
Government of South Africa should rather invest in renewable/green energy	Strongly Disagree	14	5.4%
	Somewhat Disagree	18	6.9%
	Neutral	45	17.2%
	Somewhat Agree	106	40.6%
	Strongly Agree	78	29.9%

Improved relationships between community members	Strongly Opposed	22	8.4%
	Somewhat Opposed	50	19.2%
	Neutral	49	18.8%
	Somewhat Agree	75	28.7%
	Strongly Agree	65	24.9%
Increased economic equality in communities	Strongly Opposed	31	11.9%
	Somewhat Opposed	45	17.2%
	Neutral	25	9.6%
	Somewhat Agree	103	39.5%
	Strongly Agree	57	21.8%
Shale gas development will provide the government with more tax revenue	Strongly Disagree	2	0.8%
	Somewhat Disagree	9	3.4%
	Neutral	44	16.9%
	Somewhat Agree	125	47.9%
	Strongly Agree	81	31.0%
Shale gas development will provide economic benefits to the local community	Strongly Disagree	4	1.5%
	Somewhat Disagree	40	15.3%
	Neutral	58	22.2%
	Somewhat Agree	81	31.0%
	Strongly Agree	78	29.9%
More money for the state and municipal development	Strongly Disagree	2	0.8%
	Somewhat Disagree	33	12.6%
	Neutral	6	2.3%
	Somewhat Agree	122	46.7%
	Strongly Agree	98	37.5%
Shale gas development will provide financial benefits for landowners	Strongly Disagree	70	26.8%
	Somewhat Disagree	114	43.7%
	Neutral	36	13.8%
	Somewhat Agree	23	8.8%
	Strongly Agree	18	6.9%
Financial benefits for gas companies	Strongly Disagree	55	21.1%
	Somewhat Disagree	75	28.7%
	Neutral	36	13.8%
	Somewhat Agree	57	21.8%
	Strongly Agree	38	14.6%
Reduced access to public land	Strongly Disagree	50	19.2%
	Somewhat Disagree	80	30.7%
	Neutral	31	11.9%
	Somewhat Agree	62	23.8%
	Strongly Agree	38	14.6%
Harm to wildlife and plants (Ecosystem)	Strongly Disagree	35	13.4%
	Somewhat Disagree	89	34.1%
	Neutral	36	13.8%
	Somewhat Agree	60	23.0%
	Strongly Agree	41	15.7%
Shale gas as a transition energy	Strongly Disagree	35	13.4%
	Somewhat Disagree	85	32.6%

	Neutral	51	19.5%
	Somewhat Agree	62	23.8%
	Strongly Agree	28	10.7%
A shift from coal to shale gas would benefit public health and environment	Strongly Disagree	16	6.1%
	Somewhat Disagree	37	14.2%
	Neutral	89	34.1%
	Somewhat Agree	99	37.9%
	Strongly Agree	20	7.7%
A shift from nuclear energy to shale gas would benefit public health	Strongly Disagree	13	5.0%
	Somewhat Disagree	36	13.8%
	Neutral	79	30.3%
	Somewhat Agree	81	31.0%
	Strongly Agree	52	19.9%
Reduce access to private land/land capture by government	Strongly Disagree	9	3.4%
	Somewhat Disagree	47	18.0%
	Neutral	45	17.2%
	Somewhat Agree	114	43.7%
	Strongly Agree	46	17.6%
Fracking will result in light pollution	Strongly Disagree	16	6.1%
	Somewhat Disagree	20	7.7%
	Neutral	32	12.3%
	Somewhat Agree	101	38.7%
	Strongly Agree	92	35.2%
Fracking will impact air quality	Strongly Disagree	2	0.8%
	Somewhat Disagree	7	2.7%
	Neutral	40	15.3%
	Somewhat Agree	127	48.7%
	Strongly Agree	85	32.6%
Fracking will result in noise pollution	Strongly Disagree	2	0.8%
	Somewhat Disagree	9	3.4%
	Neutral	52	19.9%
	Somewhat Agree	129	49.4%
	Strongly Agree	69	26.4%
Shale gas development will increase property/housing value	Strongly Disagree	1	0.4%
	Somewhat Disagree	9	3.4%
	Neutral	71	27.2%
	Somewhat Agree	109	41.8%
	Strongly Agree	71	27.2%
Fracking will damage the environmental aesthetics	Strongly Disagree	1	0.4%
	Somewhat Disagree	17	6.5%
	Neutral	64	24.5%
	Somewhat Agree	123	47.1%
	Strongly Agree	56	21.5%
Fracking will Impact human health	Strongly Disagree	5	1.9%
	Somewhat Disagree	61	23.4%
	Neutral	51	19.5%
	Somewhat Agree	73	28.0%

	Strongly Agree	71	27.2%
What are your major concerns/ risks regarding shale gas development	Water contamination / usage	103	39.5%
	Air contamination	38	14.6%
	Threats to existing economies (agriculture, tourism)	8	3.1%
	Impact on human health	55	21.1%
	Surface disruption	4	1.5%
	Increase in violence and crime	20	7.7%
	Loss of landscape/sense of place	19	7.3%
	Displacement/ Immigration influx	1	0.4%
	Global warming	13	5.0%
Potential benefits regarding shale gas development	Job creation	24	9.2%
	Lowering CO2 emissions	44	16.9%
	Cheap energy/ access to energy	67	25.7%
	Economic growth	57	21.8%
	Energy security	35	13.4%
	Don't know / No benefits	34	13.0%
Shale gas development will trigger an increase in migrant workers	Strongly Disagree	15	5.7%
	Somewhat Disagree	56	21.5%
	Neutral	57	21.8%
	Somewhat Agree	83	31.8%
	Strongly Agree	50	19.2%
Shale gas development will trigger an increase in the cost of living	Strongly Disagree	39	14.9%
	Somewhat Disagree	49	18.8%
	Neutral	49	18.8%
	Somewhat Agree	87	33.3%
	Strongly Agree	37	14.2%
Shale gas development will trigger competition for local businesses	Strongly Disagree	52	19.9%
	Somewhat Disagree	83	31.8%
	Neutral	34	13.0%
	Somewhat Agree	63	24.1%
	Strongly Agree	29	11.1%
Shale gas development will drive the increase in crime	Strongly Disagree	24	9.2%
	Somewhat Disagree	65	24.9%
	Neutral	62	23.8%
	Somewhat Agree	73	28.0%
	Strongly Agree	37	14.2%
Unfair gas exploration leases to oil and gas companies	Strongly Disagree	53	20.3%
	Somewhat Disagree	55	21.1%
	Neutral	38	14.6%
	Somewhat Agree	56	21.5%
	Strongly Agree	59	22.6%

Shale gas development will cause famine and shortage of water	Strongly Disagree	36	13.8%
	Somewhat Disagree	67	25.7%
	Neutral	47	18.0%
	Somewhat Agree	57	21.8%
	Strongly Agree	54	20.7%
Increase in community economic inequality	Strongly Disagree	41	15.7%
	Somewhat Disagree	74	28.4%
	Neutral	35	13.4%
	Somewhat Agree	66	25.3%
	Strongly Agree	45	17.2%
The strain on sewer/municipality facilities	Strongly Disagree	9	3.4%
	Somewhat Disagree	42	16.1%
	Neutral	40	15.3%
	Somewhat Agree	107	41.0%
	Strongly Agree	63	24.1%
Land grab/capture by government	Strongly Disagree	3	1.1%
	Somewhat Disagree	3	1.1%
	Neutral	39	14.9%
	Somewhat Agree	122	46.7%
	Strongly Agree	94	36.0%
The strain on community cohesion/place disruption	Strongly Disagree	31	11.9%
	Somewhat Disagree	54	20.7%
	Neutral	69	26.4%
	Somewhat Agree	64	24.5%
	Strongly Agree	43	16.5%
I turn to the following source for information on fracking	Television or radio news	37	14.2%
	Local newspaper(s)	69	26.4%
	People I know personally (e.g. friends, family, colleagues)	64	24.5%
	Non-news websites containing information/arguments against fracking	40	15.3%
	Environmental/anti-fracking groups via leaflets, newsletters, films or events	23	8.8%
	Social media (e.g. Twitter, Facebook)	27	10.3%
	Books, magazines or scientific journals	1	0.4%
What is the expert view on hydraulic fracking/shale gas development	Most experts agree that the risks associated with hydraulic fracking are HIGH	125	47.9%
	Most experts agree that the risks associated with hydraulic fracking are LOW	76	29.1%

	Most experts are divided on whether hydraulic fracking poses any risk or benefit	60	23.0%
How much do you know about fracking or shale gas development	A Lot	30	11.5%
	A Fair Amount	75	28.7%
	Not Sure	81	31.0%
	Not at All	75	28.7%
I support the current temporary ban on fracking in South Africa	Strongly Agree	73	28.0%
	Somewhat Agree	50	19.2%
	Neutral	56	21.5%
	Somewhat Disagree	54	20.7%
	Strongly Disagree	28	10.7%
I approve government/oil companies (public) engagement strategy concerning fracking	Strongly Agree	20	7.7%
	Somewhat Agree	46	17.6%
	Neutral	54	20.7%
	Somewhat Disagree	54	20.7%
	Strongly Disagree	87	33.3%
I support stringent regulation on fracking in South Africa	Strongly in Support	43	16.5%
	Somewhat in Support	136	52.1%
	Neutral	46	17.6%
	Somewhat Oppose	26	10.0%
	Strongly Oppose	10	3.8%
More research is needed on fracking to better understand potential risks and benefits	Strongly Agree	79	30.3%
	Somewhat Agree	106	40.6%
	Neutral	39	14.9%
	Somewhat Disagree	24	9.2%
	Strongly Disagree	13	5.0%
What is your preferred energy source	Coal	37	14.2%
	Nuclear	8	3.1%
	Solar	67	25.7%
	Natural Gas	72	27.6%
	Offshore wind	77	29.5%
Likelihood of fracking operations to be properly regulated in South Africa	Very Likely	26	10.0%
	Somewhat Likely	91	34.9%
	Neutral	48	18.4%
	Somewhat Unlikely	54	20.7%
	Very Unlikely	42	16.1%
Fracking will occur in or near my neighbourhood	Very Likely	10	3.8%
	Somewhat Likely	31	11.9%
	Neutral	79	30.3%
	Somewhat Unlikely	91	34.9%
	Very Unlikely	50	19.2%
Valid		261	100.0%
Missing		0	
Total		261	

Summary of Eta Squared (One Way ANOVA)

Level of Support of Shale Gas Development

Tests of Between-Subjects Effects

Dependent Variable: Ethnic Groups

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	41.797[a]	4	10.449	8.961	.000	.123
Intercept	487.505	1	487.505	418.049	.000	.620
Support/ Oppose	41.797	4	10.449	8.961	.000	**.123**
Error	298.532	256	1.166			
Total	2191.000	261				
Corrected Total	340.330	260				

a. R Squared = .123 (Adjusted R Squared = .109)

small .01 or 1%

• Medium .06 or 6%

• Large .138 or 13.8%

- **.01:** Small effect size
- **.06:** Medium effect size
- **.14 or higher:** Large effect size

.123 moderate

.089 small EneSource

.155 large Awareness

.087 small NIMBY

.032 small ExptView

.229 large MonBan

.282 large Majcon

0.01 small

0.02

The interpretation values commonly in published literature are:

0.01- < 0.06 (small effect),

0.06 - < 0.14 (moderate effect) and

>= 0.14 (large effect).

Appendix 10: Summary of Codes

Codes used to analyse the respondents in the qualitative interview

Codes		Count
1a	**Attitude**	
	Support	21
	Oppose	5
b	**Moratorium**	
	Support Moratorium	22
	Oppose Moratorium	4
2	**Perception**	
	Risk outweigh Benefits	4
	Benefits outweigh Risks	22
3	**Geological and Resource Uncertainty**	
	Lack of Geological Information	15
	Structural Uncertainties	11
4	**Transition Energy**	
	Optimal Bridge	26
5	**Choice of Energy**	
	Coal	4
	Nuclear	4
	Natural/ Unconventional Gas	5
	Conventional Oil and Gas	4
	Renewables Wind and Solar	9
6a	**Environmental Impacts**	
	Water Contamination	5
	Excessive Water Withdrawal	6

	Fugitive Gas - Air Quality	4
	Earthquakes	3
	Fauna and Flora - Ecological	4
	Surface Spills and Land Degradation	4
b	**Social Impacts**	
	Influx of Migrants – Change in social identity	7
	Crime	4
	Housing	6
	Health	3
	Social Infrastructure	6
c	**Economic Impacts**	
	Crowding out	10
	Inflation and Cost of Living	16
7a	**Environmental Benefits**	
	Clean – Reduce GHG Emissions – Mitigate Local Climate Change	15
	Small Footprint	11
b	**Social Benefits**	
	Reduction in Poverty	7
	Reduction in Unemployment	19
c	**Economic Benefits**	
	Job Creation	10
	Economic Growth	9
	Cheap Energy to Produce	7
d	**Energy Security**	
	Energy Independence	13
	Access to Abundant Energy and Affordability	6
	Transition Energy	7
8	**Trust of Resource Governance**	
	High Trust	10
	Low Trust	16
9	**Source and Access of Information**	
	Peer Reviewed Scientific and Industry Sources	26
10	**Stakeholder Engagement and Social Representation**	
	Adequate	19

	Not Adequate	7
11	**Sustainability**	
	Lessons from the US	4
	Required Skills and Capacity Building	4
	Shale Boom can be Replicated	4
	Karoo Geology is Unique	5
	Regulatory and Institutional Framework	4
	Developed Best Practices	3
	Local Content	2
12	**Replication of US Shale Boom**	
	can be replicated in South Africa	13
	cannot be replicated in South Africa	13
13	**Sources of Water Contamination**	
	Biogenic Sources	15
	Integrity Failure	6
	Surface Spills	5
14	**Change of Perception and Attitude about Shale Gas Development**	
	Yes, with new empirical and industry evidence	26