This is the accepted version of this paper. The version of record is available at https://doi.org/10.1016/j.erss.2023.103068

Exploring the Role of Regime Actors in Shaping the Directionality of Sustainability Transitions in South Africa

Main and Corresponding Author
Dr Julius Omokhudu Irene
Email address: julius.irene1@gmail.com

Affiliation
Kingston University, London
Penrhyn Road, Kingston upon Thames,
Surrey KT1 2EE. United Kingdom

Second Author
Dr Mary Kelly
Email address: m.h.kelly@kingston.ac.uk

Affiliation
Kingston University
Faculty of Engineering, Computing and the Environment
School of Engineering and the Environment
Department of Geography, Geology and the Environment

Third Author
Dr Bridget Nneka Obiageli Irene
Email address: ad3587@coventry.ac.uk

Affiliation
Coventry University
International Centre for Transformational Entrepreneurship
Faculty of Business & Law
Coventry. United Kingdom

Fourth Author
Dr Kemi Chukwuma-Nwuba
Email address: ad5641@coventry.ac.uk

Affiliation
Coventry University
International Centre for Transformational Entrepreneurship
Faculty of Business & Law
Coventry. United Kingdom

Fifth Author
Dr Promise Opute
Email address: promise.opute@gpromsolutions.org

Affiliation
GProm Consultancy
Germany

Abstract

This study explored the influence of regime actors to shape the directionality of sustainability transitions. Sustainability transitions are not only limited to system design and development but an interaction of incumbent actors and path-dependent mechanisms. Policymakers may develop a strategy to steer the application of sociotechnical innovation but are faced with directionality challenges if they are explicitly focused on linear transitions. We conducted face-to-face interviews with 26 policy and technical experts to explore this concept. We base the analysis of this study on the actor's perspective, vested values, and interest to provide a basis to inform the future of sustainability transitions in South Africa. The results of the study presented divergent transition patterns across the dominant actors, creating choices for alternative pathways. The study also found considerable ambivalence about shale gas development bordering on the suitability of shale energy to facilitate the South African energy transition. This study improved our understanding of how varied interests and values of actors can present significant challenges to sustainability transitions and shapes the prospect of sociotechnical innovations.

Keywords: Directionality, Sustainability Transitions, Regime Actors, Sociotechnical Innovation, Shale Gas Development.

1.0 Introduction

The concept of sustainability transition is widely held as a defining characteristic in today's world [1, 2]. More specifically, debates about sustainability transitions have been elusive involving a broad range of concerns that differ widely in their urgency, spatial and temporal dimensions, consequences, and uncertainties [3, 4, 5]. The debates extend to the direct or indirect potential to improve the quality and well-being of humans and the environment. This paper argues that sustainability transitions should be consistent with the values, interests, beliefs, aesthetic preferences, and regime dynamics of the society [3, 6]. This characterization should be used to appraise policy choices to avoid hindering sustainability transitions. Nevertheless, to the extent that sustainability transitions foster a long-term perspective, the concept should be used to facilitate divergent viewpoints or perspectives which appear to be at variance with the conventional norm.

The way normative position and values of actors shape sustainability transition are often ignored or left out in transition discourse [6], yet we find that values and specific characteristics of regime actors vary across contexts and can evolve in different ways, driving sustainability transitions in a specific direction [7, 8, 1, 2]. Although the role and function of actors may change in a regime, actors are understood to be vital components in sustainability transitions [6]. This study defines ''regime actors as a group of actors sharing a set of rules that are unique to that regime'' [1].

We found compelling evidence in the literature that the specific values, roles, functions, and interests of actors are mostly embedded in incumbent institutions and dependencies with the potential condition to influence the directionality of sustainable transitions [9, 10, 11]. There are questions about the extent to which different directionality or alternative pathways in sustainability transitions may arise as a result of contested values and interests of regime actors and the extent to which it should require policy interventions [6, 11].

This study provides the empirical basis for the different trajectories and models of sustainable transitions. The study described the concept of sustainability transitions as impacting disciplinary fields and policy practice. More specifically, this study argues for a greater focus on the attributes of contested values and the interest of regime actors in driving sustainability transitions. Our contribution provides a stronger theoretical and empirical basis for

understanding sustainability transition pathways. The study aims to address the following research objectives:

1. Provide insight on how policymakers and technical experts respond and drive systemic change towards long-term sustainability objectives.
2. Provide a robust understanding of South Africa's systemic challenges and the need for sustainable transitions.
3. Design a framework regarding the interaction of policymakers and technical experts in shaping the specific outcome of sustainability transitions.

2.0 The Directionality of Sustainability Transitions

Development in transition studies attempts to uncover policy feedback, path dependence, and transition actors to distill policies and programs that may aid in addressing sustainability issues [7, 12, 13, 2]. However, pertinent quarries regarding ‘’who drives the transition’’, ‘’ the speed’’, ‘’the scope’’ and ‘’scale’’ of the transitions are often neglected or missing in transitions discourses [7] including the challenge to describe how contested values and interest (norms) disrupt pathways (i.e. departs from the present (conventional) state of sustainability transitions [12].While the level of destabilization builds on current trends and conceptualizations of transition pathways [14, 15], sustainability transitions add elements of contestable values and interests of regime actors [16, 13]; direction and speed of change may be divergent. Therefore fixation on a particular pathway can ‘lock in’ or ‘lock out’ alternative values and viable pathways impeding sustainability transitions. Therefore, this study suggests the concept of directionality as a defining characteristic in ‘sustainability transitions’. Contextual factors in this study refer to the nexus of social, environmental, and economic factors and the range of themes discussed in the results section (see section 7).

The framework that allowed us to assess whether the directionality of sustainability transitions is viable or not, is governed by a myriad of self-reinforcing and interlinked incumbents including actors’ values, interests, and institutional dynamics [9, 11, 17]. Forging more sustainable transition trajectories involves the consideration of both the regimes and complex panoply of values, and interests in the energy sphere [18, 19]. Therefore the trajectories of sustainability transitions will vary across contexts and unfold according to specific characteristics (contested values and interests) in the regime. The choice of directionality in a multi-dimensional space may arise from conditions of path dependency, actor’s perspective,

and technological possibilities. Therefore, sustainability transitions may develop along different pathways at the national, regional, or global scale [20, 2].

Therefore this study contributes to conceptualizing the dynamics, speed and directions in which sustainability transitions can develop. We provide empirical examples involving technical experts and policymakers to illustrate our conceptual contribution where the directionality of sustainability systems resulted in the emergence of fast and slow transition (see the section in this study on the discussion on the sense of directionality of sustainability transitions).

Combined with this insight, the outcome presented in the study supports policymakers interested in promoting and exploring the directionality of shale gas development in South Africa with an understanding of the technical, environmental, social, and economic merits of developing the shale resource as a 'bridge fuel' and implications to the energy transition in South Africa.

3.0 The Energy Landscape of South Africa

South Africa's power sector is facing significant challenges [21, 22, 23]. Access to reliable, affordable, and sustainable electricity is required to transform the development of the country [24]. As the country grapples with these urgent challenges, natural gas could offer a new baseload to address the country's CO_2 emissions in the short term, energy shortage, and enable the penetration of renewables [25, 26, 27]. Beyond this, the switching of coal to shale gas presents an opportunity to retire the country's aging coal power fleets ensuring a sustainable pathway that will stimulate economic growth, create job prospects, and spur industrialization of the country [28, 22].

While there is no universal strategy and approach for transitioning from coal-to-gas power, references exist in countries like China, Viet Nam, India, Indonesia, and Mongolia demonstrating the socioeconomic effects of shifting to low-carbon energy [30]. Coal accounts for more than 86% of the South African energy mix and presents a significant risk to the country's decarbonization efforts [31, 32]. Addressing South Africa's energy demand and CO_2 emissions are the key drivers for the changing energy landscape [33, 34, 23]. The country revised Integrated Resource Plan (IRP) aims to decommission 11 GW of coal-generated electricity by 2030 with a mix of renewables [34, 29]. However, South Africa cannot depend solely on green energy to mitigate both the challenges of climate change and economic drive industrialization [35]. South Africa will need to grow variable levels of natural gas and

renewables in the energy mix even as coal continues to play a dominant role in generating electricity (Figure 1).

Studies have demonstrated that gas-fired electricity plants generate lower CO_2 emissions (<320g /kwhr) than coal and other fossil fuels (ca 1000g /kwhr) showing it as an alternative energy low carbon source [37, 38]. Gas-fired plants are operationally flexible at scale and easily deployed to accelerate the decarbonization of the energy grid [39].

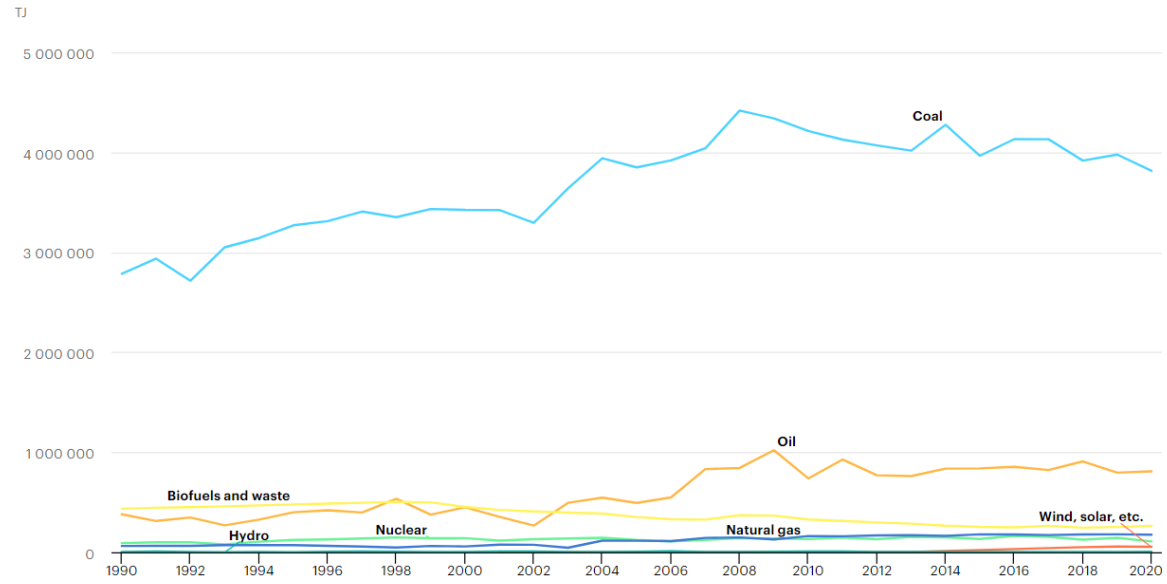

Figure 1: South Africa's Electricity Generation by Energy Source. Source: [36].

South Africa could draw lessons from energy policy reforms in China to accelerate coal fire electricity to the gas energy transition, accompanied by the use of carbon capture sequestration (CCS) and hydrogen technologies [40]. The deployment of these technologies incorporating gas-generated electricity presents a cost-effective strategy and optimal bridge fuel to support South Africa's decarbonization agenda.

Recent offshore gas (Brulpadda gas condensate and Luipend-1X well) discoveries in South Africa and reserves of shale gas resources in the Karoo Basin [41] (Figure 2) could be a 'game changer' and a baseload for gas-generated electricity in the country [42, 29]. Nonetheless, the commercialization of these assets is far from development due to operational, infrastructural, and political uncertainties in the country [43]. South Africa needs 4–6 GW of electricity in the short term to mitigate current load shedding [29]. Thus, financing for the country's lower

carbon fossil fuel gas power projects is critical to increasing reliable electricity supply and transforming into a low carbon resilient economy.

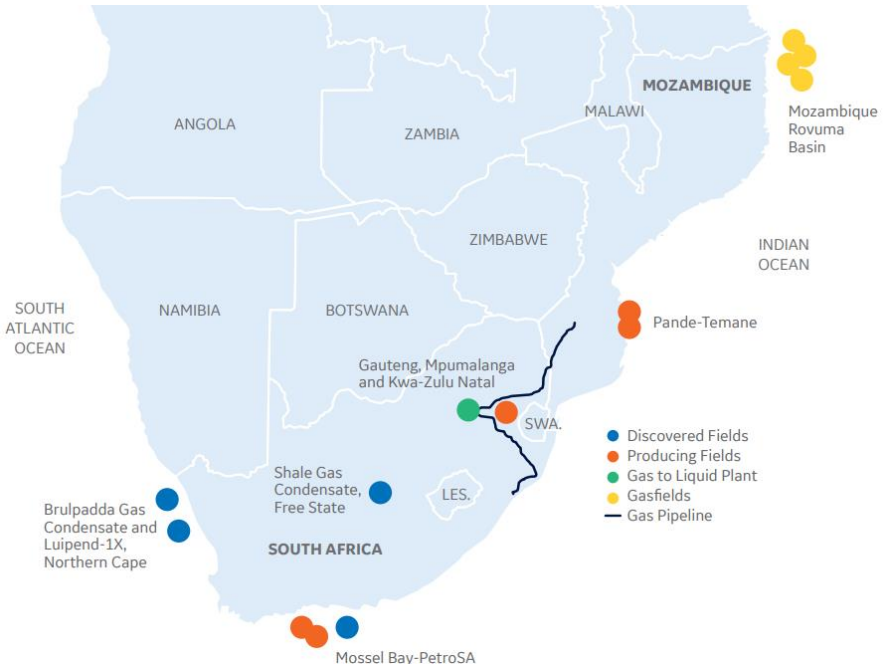

Figure 2: Gas reserves in South Africa Source: [43].

Policy decision on Shale gas development is an emerging field of interest, focusing on the concerns that have prevented the shale gas industry from been widely accepted as a sustainable energy resource [41, 44, 45]. Issues related to the potential long term social, health, and environmental impacts of shale gas development [46, 47] and the appropriate system of risk governance continued to shape negative perception of the shale technology [48, 49].

South Africa is undergoing a transition from a coal-based economy to renewables [50, 51]. The energy transition policy of South Africa explores how shale gas can be deployed as a 'bridge fuel' in the decarbonization pathway [42, 47, 29]. The need for urgent climate change mitigation and access to both reliable and affordable electricity requires greening the power generation mix with available energy sources. The South African Climate Change Bill and Nationally Determined Contribution (NDC) specify a significant commitment to meeting these objectives [52]. This is a step in the right direction given that South Africa is the 12th-largest emitter (per capita) of global greenhouse gas (GHG) emissions intensity and the highest in Africa [52]. In this context, a structural and criteria framework approach is designed to reduce

17 % of CO_2 emissions by 2025 and 32 % by 2030, representing 398 to 614 $MtCO_2e$ million tonnes of CO_2 equivalent in 2025 and 2030 [53. 52] Fig. 1.

The role of shale gas in the energy transition has raised concerns from energy experts and policymakers [54, 55, 47]. Studies have indicated that shale gas if properly managed, has low carbon footprint than the other fossil fuels [56]. The development of carbon capture storage systems (CCS) plays an increasing role in mitigating carbon emissions in hard-to-abate sectors and large point sources [57, 58, 59, 60].

4.0 The Influence of Regime Actors on Sustainability Transitions

[61] highlights three mechanisms by which regime actors influence the direction of sustainability transitions; maintain the existing regime, disrupt/ destabilize the regime or create new niches for the emergent technology [62, 63]. This implies that sociotechnical systems may take different shapes and directions [64, 65]. Studies suggest that transitions are non-unidirectional or linear processes but develop from both the influence and interaction of multiple actors and institutional systems [66, 67, 68]. These interactions reflect a range of varied configurations and spatial geographies of nested values, and interests embedded within the incumbent regimes. The 'actor-based approach' becomes an appropriate tool to analyze the directionality of sustainability transitions because it shifts the emphasis from a 'technology fix' to a fundamental change in systems designed to achieve societal needs [69, 70, 71, 72, 73]. The 'actor-based approach' focuses on the local manifestation in addressing sustainability challenges through meaningful interaction in the local context offering alternative ideas to advance sustainability transitions [74]. Based on a focused literature review on the directionality of sustainability transitions, this study explores how policymakers and technical experts shape their perspectives of sustainability transition in South Africa [62, 66, 68, 74].

5.0 Theoretical Framework

Transition frameworks are important tools for framing the way transition unfolds and are valuable in planning the pathways of sustainability transition [75]. They are an important tool for improving our understanding of the dynamics of transitions including managing uncertainties in sustainability transitions [76, 75]. In all, transition frameworks are useful models in identifying and theorizing the interaction of relevant actors, institutional systems, and path-dependent mechanisms (such as 'lock-ins'), this allows us to find out if the interaction leads to a very specific outcome or produces an emergent pathway [14,77, 78].

In the context of the sustainability transition in South Africa, we focus on understanding the interaction of the dominant actors and processes and how that becomes sufficiently significant to destabilize the prevailing regime to create new pathways. We define a regime' in this study as the aggregation of shared norms, rules, and practices influencing the adaptation of actors [79]. Building upon this, the theoretical framework used in this study (Fig. 3) captures the complexity and multi-dimensionality of sustainability transitions with a particular focus on regime actors (policymakers and technical experts). The framework also presents divergent transition patterns across the dominant actors, creating choices for alternative pathways. Figure 3 depicts the dynamics of transition processes arising from the interplay of developments at three analytical levels: actor, 'lockin' mechanism, and directionality.

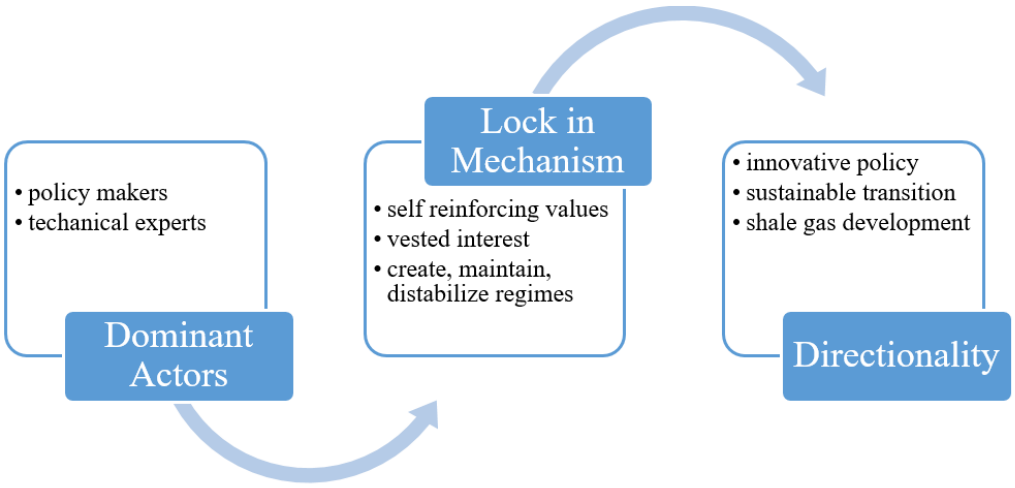

Figure 3: Theoretical Framework

6.0 Methodological Approach, Collection, and Analysis

Unlike most sustainability transition studies that are systematic in design [80, 81, 82], the methodological approach employed in this study is planned to be more descriptive, exploratory, and interpretative than systematic. This paper is based on original empirical work on sustainability transitions using qualitative methodology to explore the interrelated influences shaping the responses of incumbent actors to the sustainability challenges in South Africa, detailing the salient themes and experiences of the actors. The participants for this study were purposively selected as existing actors in the energy industry (Table 1). This study applied the definition of incumbent actors to select the participants as influential and established

individuals responsible for leading sustainability change and niche innovations in the energy industry in South Africa [83, 84].

Semi-structured interviews comprising 13 policymakers and 13 technical experts were conducted face-to-face with each interview lasting about an hour (Table 1). Semi structure interviews have the benefit of investigating both salient and unobservable factors [85]. The interviews were conducted in English, audio recorded, and transcribed in Nvivo version 12 software. The study examined the role and perspective of the actors including the institutional work they engage in to shape the directionality of the energy transition. A list of interviewees is provided in Table 2.

The demographic characteristics of the study sample are presented in Table 2.

Table 1: Classification of Participants

Participants Interviewed	**Description of Participant**	**Number of Participants (n 26)**	**Sample Share (n 26) %**
Technical Expert	Senior staff from the oil and gas industry, technical, engineers, geologists, and consultancies, focused on oil and gas exploration and development.	13	50
Policy Expert	Regulators and advisers are involved in energy issues, climate change policies, and strategies. South Africa Government agencies, focused on climate and energy-related issues. Framing concerns of sustainability and the formation of local and national policies.	13	50

Table 2: Demographic Characteristics of the Qualitative Sample (ɳ26)

Variable	Number of Actors	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

Table 3 shows a summary of the interview questions. The study analysis is built on quotations and illustrations derived from the interview sessions.

Table 3: Interview Questions

S/N	Interview Questions
1	Please describe your professional background and area of your expertise.
2	What factors constitute the most critical impact assessment of shale gas development in South Africa and how do these impact South Africa's decarbonization target?
3	What is your sense of a solution to climate change?
4	What is the level of uncertainty regarding the current level of knowledge of each factor?
5	What is your concept of 'bridge fuel'? Do you consider shale gas as the optimal transition energy?
6	Can these uncertainties be mitigated? How can decision-makers operationalize these mitigations?
7	How can decision-makers build an effective and fit-for-purpose framework to guide the energy transition?
8	What explains your sense of directionality of sustainable transition in South Africa?

6.1Thematic and Content Analysis

The interviews were transcribed and inputted into Nvivo software for thematic and content analysis. The study adopted a coding strategy and generated a balanced code tree that captures the underlying factors shaping the viewpoints of the participants.

The transcripts were coded manually to pinpoint emerging themes arising from the interviews and to examine if the themes reflected the dominant views of the actors – technical experts and policymakers. The codes were reviewed severally to produce a balanced perspective of dominant themes. The coding process involved categorizing and reviewing participants' responses to each of the questions to extract the final set of descriptive and final themes to reflect the perspectives of the - technical experts and policymakers. The final themes are represented in Figure 4. Some literal and relevant quotations from the participants are presented in the study.

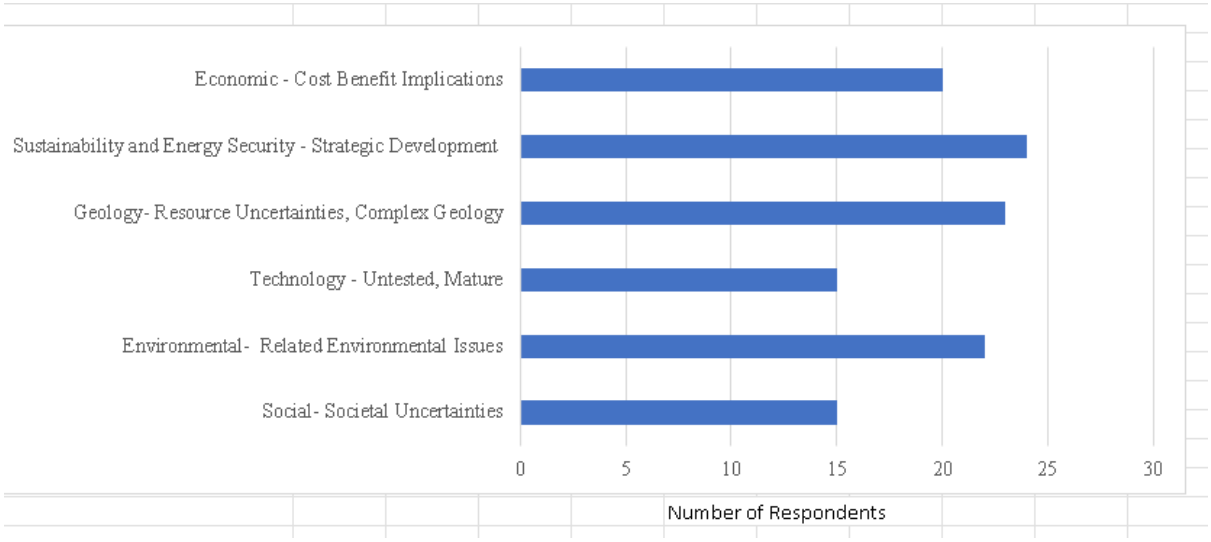

Figure 4: Responses to Dominant Themes

7.0 Results of the Study

7.1 Thematic Inductive and Process of Analysis

This paper provides the groundwork for further qualitative study in sustainability transitions in South Africa and similar sociocultural contexts. We recognized that human behavior is shaped by the interaction of social structures/ conditions, risk perception, and protective human behavior [85, 86]. It was important to strengthen the quality of the analysis by improving the

logical flow and rigor of the coding process in order to compare codes, identify patterns of emerging themes in the data.

We mapped clusters of keywords and common themes that reflected the novelty of factors among the network of actors influencing the directionality of the energy transition in South Africa. The key themes received equal amounts of consideration allowing us to build a theoretical foundation and thematic prediction model for this study. The evolutionary pathway cited in Figs. 5 and 6 allowed us to define the thematic boundaries, and visualize the dynamic development, characteristics, and semantic relationships among the key themes. This development allowed us the opportunity to avoid subjective judgments and potential randomness commonly found in most qualitative studies [87, 88, 89, 90. Based on the aforementioned common themes identified, the study combined references of quotes from interviewees. The response from the qualitative interviews indicates divergent positions about sustainability energy transitions with contending perceptions regarding the risks and benefits of developing the shale resource in the Karoo Basin (Figures 5 & 6).

The emerging themes were categorized under six themes: Geology, Technology, Environment, Social, Economics, Sustainability, and Energy Security illustrating an overview of what the participants collectively considered as dominant themes. The dominant themes to emerge from the interview are: Sustainability and Energy Security, Geology and Resource Estimates, and Environmental related issues were used to explore the competing themes and context for the study.

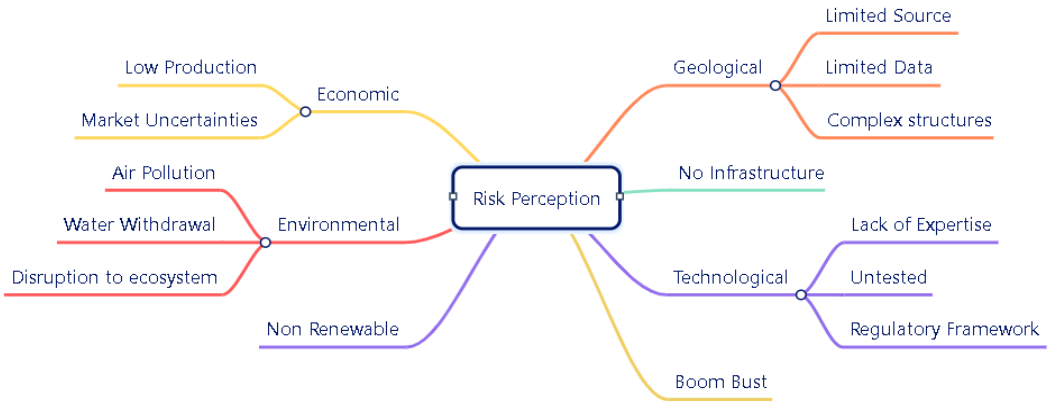

Figure 5: Thematic Map Showing Perception of Risks
The arrows demonstrate networks between the key themes. The path of the arrows suggests whether a theme facilitates another theme.

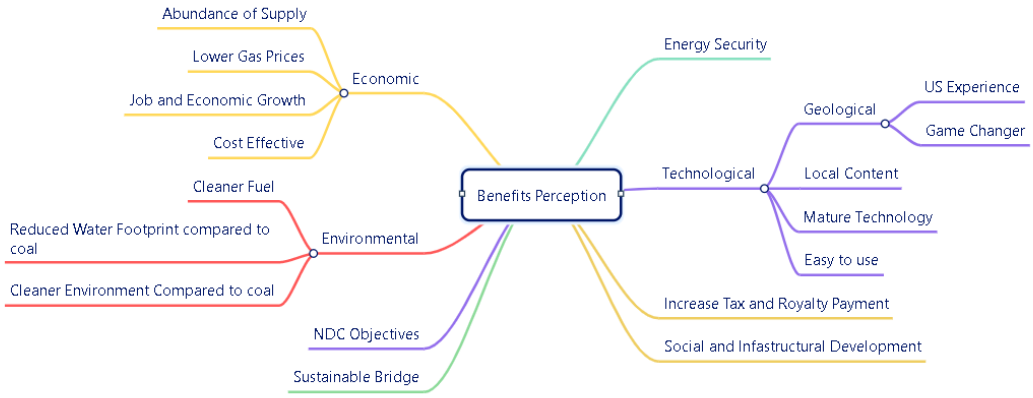

Figure 6: Perception of Benefits

The arrows demonstrate networks between the key themes. The path of the arrows suggests whether a theme facilitates a subtheme.

7.2 Economic Factors

Economic growth, job creation and affordable energy access were highlighted by the policymakers as key benefits of shale gas development and critical metrics of sustainable development. The policymakers noted that shale gas development will facilitate the broader social agenda to improve the well-being and living standards of people in the Karoo. The technical experts' highlighted significant uncertainties in scaling the development of shale gas sustainability in the long term noting that most shale wells deplete very quickly. There was a consensus to integrate the proceeds from shale gas development as sovereign funds and investment and develop the local socio-economic programs such as the farming and manufacturing sector. The Technical experts also highlighted the geological and structural constraints of encountering commercial volume of gas in the Karoo basin to encourage significant investment in shale gas development.

''The government has conducted several feasibilities and scientific studies that suggest a favorable economic and energy security outcome of developing the Karoo shale reserves".

Male, Policy Experts, 41 years.

''Shale gas development could be a game changer for South Africa should commercial quantities of shale gas found in the Karoo Basin".
Male, Technical Expert, 50 years.

7.3 Social Factors

The technical experts highlighted the social license to operate as a key consideration and implication for shale gas development. They also noted that greater transparency, consulting with the locals, and incorporating stakeholder views are needed to make progress and there has not been sufficiently demonstrated. The technical experts pointed out that public acceptance of shale gas development can only be achieved if energy policy is aligned with the social agenda of the various ethnic groups in the Karoo. The technical experts highlighted the impact shale gas development could have on South Africa's fragile social fabric if not properly managed. The policymakers highlighted that the social and governance-specific components of shale gas development in South Africa are aligned with the social and economic well-being of the people.

''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.

''I believe that the institutions in the country are built on a high level of fairness, and 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.

7.5 Technological Uncertainty

New and unfamiliar technologies such as shale gas development provoke a sense of deep uncertainties among technical experts. However, the expert view was mixed regarding the risks and role shale gas development could play in the decarbonization agenda of South Africa. The technical experts advocated the precautionary strategy as a means of mitigating the uncertainties of shale gas development given that the shale technology is nascent in South Africa. However, the policy experts noted that potential delays in deploying the shale gas technology could be costly in establishing South Africa on the energy map and deprive the country of huge economic gains given the favorable energy market. The experts expressed challenges in restructuring historic coal power infrastructure with gas pipelines and facilities.

''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 favorable geological features, strong regulatory and institutional framework, established infrastructural and market conditions, and advanced technological capabilities. South Africa does not have the conditions to replicate the benefits of shale gas development as America does. 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 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.

''Exploration and development of shale gas in South Africa are 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.

7.6 Geological Factors

The strength in agreement (81% agreed) in support of shale gas development was in part a result of enormous policy and legislative responses to the decarbonization of the economy, a boost for economic growth, job creation, and a feedstock for electricity generation in the country. This includes the 2010 Integrated Resource Plan of having an electricity mix that incorporates gas as a backup to the renewable energy roll-out plan [91]. Successive circles of fiscal projections have continued to give a sense of the potential of shale gas development of a similar magnitude to the American shale revolution [92, 47]. Despite the consensus and support for shale gas development among the experts (mainly policymakers), 19% of participants disagreed with lifting the moratorium based on potential environmental risks, and underlying structural and geological uncertainties in the basin highlighting the difficulty to replicate the American shale revolution elsewhere.

The technical experts noted that the scale of geological risks regarding the Karoo resource potential presents significant uncertainties to shale gas development. The technical experts noted that the knowledge gap in Karoo geology also presents a limiting factor for effective decision-making regarding the commercial potential of the basin. The technical experts noted more stringent science-based policy-making on actual drilling activities and comprehensive technical investigations to de-risk the Karoo Basin. The absence of good geological information will inform poor planning, long term environmental and economic consequences. The policy experts maintained that the benefits outweigh the potential risks, and studies suggest an upside potential of significant economic recovery and robust policy decisions. There was consensus among the participants regarding lifting the moratorium, the technical experts noted that lifting the moratorium offers the opportunity to obtain actual geological data to appraise the geological basin. The policymakers noted that lifting the moratorium is good to accelerate energy development.

''It makes sense to lift the moratorium in order to fast-track energy development. The country risks natural asset straddling which could set South Africa behind in terms of industrialization and economic growth.
Male, Policy Maker, 45 years.

"While uncertainties exist in the Karoo shale resources, the moratorium over exploration of shale gas assets should be lifted. Lifting the moratorium will allow us to access the full potential of the basin".

Male, Technical Expert, 42 years.

7.7 Environmental and Sustainability Factors

The broad range of benefits and challenges of transitioning to a sustainable energy future using shale gas development was a key aspect of the interview. Concerns were raised about the potential social, economic, environmental, and health consequences of developing the shale gas industry and whether the development of the shale gas industry would be compatible with South Africa's climate change mitigation plan. The policymakers pointed to the potential benefits of shale gas development – for the South African economy, energy security, and driving investment in a wide range of social and environmental benefits.

The majority of the policy experts noted that shale gas is an innovative solution to mitigate climate change and energy challenges and improve access to affordable energy. The policy experts noted that shale gas development is a potential component of sustainable development bringing job creation and economic growth.

The technical experts described sustainability as an evidence-based innovation in contrast to the policymakers who defined sustainability as an adapted practice incorporating local perspectives. The technical experts noted that shale gas is a finite energy resource and only sustainable development brings job creation and economic growth requiring a cautious and evidence-led approach to exploring the potential risks, benefits, and challenges of exploring the Karoo Basin, as it considers the opportunity of developing the shale gas industry in South Africa.

''Sustainability encompasses the capacity to deliver natural resources over time with minimal risks or harm to the environment".

Male, Technical Expert, 50 years

''Sustainability is adapting innovation or natural resource to the local environment in the short or long term".

Male, Policymaker, 45 years

''Decline of peak production of shale gas is likely to be dramatic over a short life cycle making it one of the least sustainable options for economic and energy development ."

Female, Technical Expert, 36 years.

'' Scenarios exist where shale gas was developed sustainably bringing in huge economic, social and environmental benefits and helping to fulfill the energy need of society".

Female, Policy Expert, 40 years.

7.8 The Framing of Risk Perception by the Experts

Risk perception is a subjective psychological concept that defines the probability and severity of a risk and varies between individuals and social groups [93, 86, 94]. The cognitive assessment involved in risk perception depends on several factors such as exposure to the risk, quality of information, trust, awareness, and familiarity with the risk [95,96,97]. Risk perception is also influenced by sociocultural factors and values [98, 99]. The participant's perception of risk was influenced by a shared awareness of sustainability transitions and spanned several domains and contextual factors, including protective behaviors, and environmental, economic, social, and technical considerations. Even though the participants have no direct experience with shale gas development, however, the perception of the participants seems to be influenced by the quality of information concerning the range of uncertainties and benefits related to shale gas development. The perceptions of shale gas development are expressed as a complex interplay of the potential benefits and risks associated with shale gas development. The finding of this study further suggested that participants in support of developing the shale industry see potential value in the industry to address the energy and economic challenges of South Africa. The study also discovered that perceptions about the

shale industry are related to the participant's wider behavior toward the long-term effects of shale gas development on the environment and regulatory framework in managing the industry.

The participants expressed a strong distinction in their perception and analysis using a clear language of scientific uncertainty as a feature of shale gas development. The difference in perception between the technical experts and policymakers aligns with previous studies concerning how scientific uncertainty is used to frame the values and interests of incumbent actors [100,101,102]. It does take into consideration alternative framings of concerns.

The technical experts expressed reservations in different aspects of shale resource development in contrast to the Policymakers who noted scientific certainties within the context of sustainability transitions. However, the critical view held by the experts on decarbonization was unanimous. The quotes highlight the notion of climate change as an environmental concern. We noted that the characterization of sustainability transitions adopted by the Policymakers and Technical experts has implications for policy and decision-making.

''I see significant value in developing the shale industry – notably in mitigating climate change and energy insecurity – I believe that the potential long-term risks are generic and do not apply to the South African context".

Male, Policy Maker, 42 years.

''There is no doubt that shale gas development offers some short-term economic benefits, however, drawing from the US experience suggests that the potential benefits are accompanied by long-term economic, social, and environmental risks".

Male, Technical expert, 46 years.

7.9 Perceptions of Shale Gas Development

Shale gas development is an intense and complex engineering technology [94]. Despite the potential benefits of shale gas development as a move toward sustainable energy development [103]. Studies argued that the process induces severe environmental, economic, and social risks

[104,47]. This study showed that risk perception played an important factor in shaping expert behavior concerning shale gas technology. The experts conceptualized risk as the likelihood of undesirable consequences of shale technology. The participants noted multiple undesired consequences and different levels of severity for any given condition in contrast to general impacts provided by extant studies.

The policy experts noted that the potential benefits of shale gas development outweigh the perceived risk and therefore demonstrated significant support (81%) of the shale technology, while 19 % of the participants opposed shale technology. The policymakers noted that shale gas presents many advantages over coal as the cleanest burning fuel of all fossil resources. The opinion of the technical experts about the risks and benefits of shale gas in South Africa was divergent from the policy experts. The technical experts noted that shale gas development is still at the nascent phase of exploration, hence risks and benefits tend to be difficult to understand. The technical experts cautioned that South Africa was very different (geologically and in regulatory context) from the US, rendering the lessons not entirely useful, while the policy experts seemed to see the US as a useful example. This discussion seems to present a divergence in opinion regarding a transition path for shale gas.

''The success of shale gas development in the US is due to a combination of factors such as favorable geological and regulatory environment compared to the Karoo Basin which has many structural and geological risks. While lessons from the US are good but they cannot be replicated in the South African context. Shale gas development in South Africa presents much higher risks than benefits.

Male, Technical expert, 40 years.

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

7.10 Perceptions and Attitudes towards Moratorium

The majority of the participants (mainly Policymakers) agreed that the moratorium on shale gas development should be lifted. These findings support those who support the development of shale gas in South Africa. The findings of this study found that the potential risks associated with shale gas development as the most important factor influencing the perception of policymakers in support of the continuous moratorium on developing the shale industry. Furthermore, the participants believed that evidence-based data were required to lift the moratorium due to the presence of geological and structural uncertainties in the Karoo Basin. Other participants (mainly Technical Experts) noted that the lack of evidence data about the potential risks and structural uncertainties does not indicate an over-cautious assessment of shale gas development in South Africa. The participants believed that the lessons learned about the success of shale gas development in the US are instructive for lifting the moratorium on shale gas development in South Africa.

We should be prioritizing shale gas development in our energy transition plan, not only would shale gas meet our clean energy demand but also create economic opportunities for the local people".

Male, Policy Expert, 45 years.

''Exploration and development of shale gas in South Africa is a complex venture. The benefits of shale gas development are significant for South Africa, however, it is important to pursue the development of the shale resource cautiously".

Male, Technical Expert, 50 years.

8.0 Lessons from Sustainability Transitions in South Africa

The study explored how policymakers and technical experts shape their perspectives on sustainability transitions in South Africa. The study demonstrated that the scope and geographical applications of sustainability transitions have broadened to provide a comprehensive understanding of the challenges related to sustainability transitions and societal challenges such as climate change and natural resource management. These challenges cannot

be solved linearly or by technological fixes but by radical shifts in socio-technical systems and the broadening of alternative perspectives [80, 81]. The study conceptualized how alternative directionality can unfold in a low-carbon energy source such as shale gas development. We argue that policymaking plays a critical role in framing the directionality of sustainability transitions through dynamic processes [11]. Supporters of the fast transition pointed out that sustainability policy will need to take advantage of technological innovations to mitigate climate change. They noted that shale gas development provides the opportunity to drive sustainable policies without imposing significant costs on society. Despite the urgent need to tackle decarbonize the economy, supporters of the slow transition noted that the transition must proceed at a variable speed, equitable, and specific in addressing the challenges of transforming South Africa's energy mix (Fig. 7).

''We need to adopt a transition that fits South Africa's energy, socioeconomic, and environmental context. Leapfrogging the transition will undermine South Africa's economic development".

Male, Technical Expert, 49 years.

''The energy transition is a crucial enabler of sustainable development and climate resilience. An opportunity for South Africa to fast track economic and social development".

Male, Policymaker, 40 years.

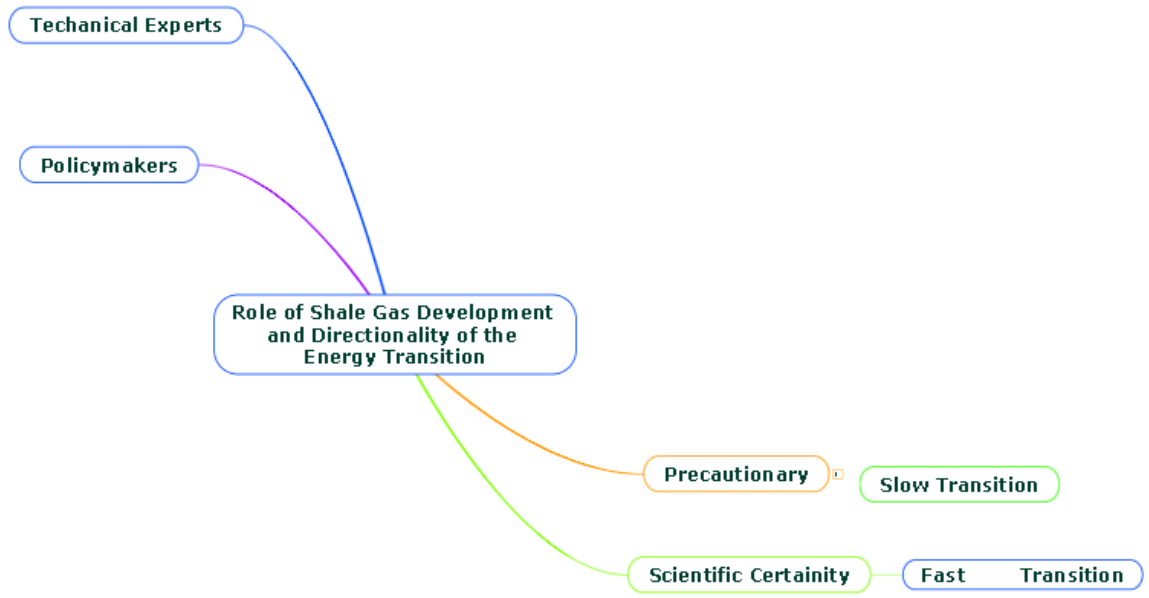

Figure 7: Directionality and sense of shared direction in guarding the energy transition.

9.0 Discussions and Implications of the Findings

Empirical work on what constitutes the directionality of sustainability transitions in South Africa is still unclear and unmapped. Directionality is important as it shapes the alignment of mission-oriented innovation systems and steers transformation in a specific direction [105, 106]. Without a clear and systematic analysis of directionality (actors who influence "current system mechanisms'', solutions to sustainability and development challenges such as climate change may not be facilitated [105, 106].

This study explores the role of policymakers and technical experts in shaping the directionality of sustainability transitions in South Africa, revealing its core features, dynamics, and implications. The paper also provided a facet of emerging themes and critical junctures for paving the way to sustainability transitions in South Africa. This study captures the pace, patterns, and dynamics of sustainability transitions and provides a good understanding of how the energy transition can be governed in the face of emergent factors and incumbent actors. Policy support must acknowledge the way transitions unfold, both in terms of speed and direction, taking into account the vested interests and values of incumbent actors.

The study demonstrated that regime actors implement varied perspectives of sustainable transition. For example, the technical experts supported a precautionary position in the diffusion of shale gas development in contrast to policy experts who demonstrated a significant posture of certainty and legitimacy in developing shale gas to advance a fast transition (Figure 7). These differences in perspective and interactions contrast with the conventional understanding in sustainable transition studies where actors are thought to sustain the prevailing institutional and sociotechnical regime [107, 63]. Moreover, all the actors actively share their perspectives and positive associations of increasing the share of renewables in the energy mix as the long-term sustainability focus.

This study provides important insights into the critical uncertainties bordering on the suitability of shale energy to facilitate the South African energy transition. We found considerable ambivalence about shale gas development, but also greater awareness of potential benefits than risks. 81% of the participants (mainly policy experts) maintained the support of shale gas development while 19% opposed the development of shale resources. This is logical given that unconventional energy technologies are complex and contested by differing experts. However, policymakers can glean from this to develop an adaptive framework to support strategic policymaking and responses to the challenges of shale gas as a 'bridge fuel' in the transition pathway.

Participants' emphasis on the lack of clear empirical evidence about the long-term risks associated with shale gas development shows an over-cautious view of developing the shale industry. Others suggested that policymakers and regulators need to learn from the US shale experience in order to understand the trade-offs involved in realizing the benefits of shale gas development.

10.0 Limitations of the Study

A key limitation of the semi-structured interview is the tendency of the participants to exercise their perceptions and experiences in a more positive context without consideration of alternative perspectives enforcing the assumption that experts are likely to present a parochial and narrow-minded perspective of a complex situation. These seemingly contradictory assumptions were resolved by presenting the same questions in order to achieve objective responses and aggregating the opinions of the experts.

11.0 Summary and Conclusion

The energy transition focuses on the urgent need to address climate change and accelerate a shift to renewables. While the sustainability transition is underway in the Global North, however, the energy transition is challenged in countries that are heavily dependent on fossil fuels. More evidence is emerging regarding the multifaceted challenges and structural barriers impeding sustainable transition in developing economies such as South Africa.

The challenges faced by South Africa are multi-faceted and linked in complex ways to prevailing energy, environmental, social, economic, and infrastructural systems, making it rigid to achieve rapid fundamental transitions. Against this backdrop, this study concludes that South Africa must adopt incremental transformations involving transitions in dominant institutions, practices, policies, and technologies while safeguarding a long-term sustainability agenda [108]. This is consistent with historical case studies which support a 'punctuated equilibrium' pathway, entailing extended periods of incremental sociotechnical transformation interspersed with fairly short phases of disruption in transitions [109, 110, 111].

Whilst there are substantial potential benefits associated with shale gas development, however, there are concerns about the potential risks of developing the shale industry over the long term. Policymakers face the challenge of balancing these potential risks and benefits. Therefore, this study is imperative as it provides questions about whether current South African policy frameworks are suitable to manage the shale industry.

Disclaimer

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

12.0 References

[1] Ramanauskaitė, J., 2021. The Role of incumbent actors in sustainability transitions: a case of Lithuania. Sustainability, 13(22), p.12877.

[2] Andersson, J., Hellsmark, H. and Sandén, B., 2021. The outcomes of directionality: Towards a morphology of sociotechnical systems. Environmental Innovation and Societal Transitions, 40, pp.108-131.

[3] Marshall, J.D. and Toffel, M.W., 2005. Framing the elusive concept of sustainability: A sustainability hierarchy. Environmental science & technology, 39(3), pp.673-682.

[4] Kemp, R. and van Lente, H., 2013. The dual challenge of sustainability transitions: different trajectories and criteria. In Innovations in Sustainable Consumption (pp. 115-132). Edward Elgar Publishing.

[5] Genus, A., 2016. Sustainability transitions: a discourse-institutional perspective. In Handbook on Sustainability Transition and Sustainable Peace (pp. 527-541). Springer, Cham.

[6] Fischer, L.B. and Newig, J., 2016. Importance of actors and agency in sustainability transitions: a systematic exploration of the literature. Sustainability, 8(5), p.476.

[7] Stirling, A., 2009. Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development, STEPS Working Paper 32, Brighton: STEPS Centr.

[8] Weaver, P.M. and Jordan, A., 2008. What roles are there for sustainability assessment in the policy process?. International Journal of Innovation and Sustainable Development, 3(1-2), pp.9-32.

[9] Berkhout, F., Smith, A. and Stirling, A., 2004. Socio-technological regimes and transition contexts. System innovation and the transition to sustainability: Theory, evidence and policy, 44(106), pp.48-75.

[10] Foxon, T.J., Hammond, G.P. and Pearson, P.J., 2010. Developing transition pathways for a low carbon electricity system in the UK. Technological Forecasting and Social Change, 77(8), pp.1203-1213.

[11] Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F. and Fünfschilling, L., 2019. An agenda for sustainability transitions research: State of the art and future directions. Environmental innovation and societal transitions, 31, pp.1-32.

[12] Lindberg, M.B., Markard, J. and Andersen, A.D., 2019. Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. Research policy, 48(10), p.103668.

[13] Turnheim, B. and Sovacool, B.K., 2020. Exploring the role of failure in socio-technical transitions research. Environmental Innovation and Societal Transitions, 37, pp.267-289.

[14] Geels, F.W. and Schot, J., 2007. Typology of sociotechnical transition pathways. Research policy, 36(3), pp.399-417.

[15] Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M. and Wassermann, S., 2016. The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Research policy, 45(4), pp.896-913.

[16] Schlaile, M.P., Urmetzer, S., Blok, V., Andersen, A.D., Timmermans, J., Mueller, M., Fagerberg, J. and Pyka, A., 2017. Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. Sustainability, 9(12), p.2253.

[17] Van Mierlo, B. and Beers, P.J., 2020. Understanding and governing learning in sustainability transitions: A review. Environmental Innovation and Societal Transitions, 34, pp.255-269.

[18] Cowell, R., Ellis, G., Sherry-Brennan, F., Strachan, P.A. and Toke, D., 2017. Sub-national government and pathways to sustainable energy. Environment and Planning C: Politics and Space, 35(7), pp.1139-1155.

[19] Simmie, J., 2012. Path dependence and new technological path creation in the Danish wind power industry. European Planning Studies, 20(5), pp.753-772.

[20] Pel, B., Raven, R. and van Est, R., 2020. Transitions governance with a sense of direction: synchronization challenges in the case of the dutch 'Driverless Car'transition. Technological Forecasting and Social Change, 160, p.120244.

[21] Andrade, J.V., Salles, R.S., Silva, M.N. and Bonatto, B.D., 2020, August. Falling consumption and demand for electricity in South Africa-a blessing and a curse. In 2020 IEEE PES/IAS PowerAfrica (pp. 1-5). IEEE.

[22] Linton, S., Clarke, A. and Tozer, L., 2022. Technical pathways to deep decarbonization in cities: Eight best practice case studies of transformational climate mitigation. Energy Research & Social Science, 86, p.102422.

[23] Nogaya, G., Nwulu, N.I. and Gbadamosi, S.L., 2022. Repurposing South Africa's Retiring Coal-Fired Power Stations for Renewable Energy Generation: A Techno-Economic Analysis. Energies, 15(15), p.5626.

[24] Khan, I., Zakari, A., Zhang, J., Dagar, V. and Singh, S., 2022. A study of trilemma energy balance, clean energy transitions, and economic expansion in the midst of environmental sustainability: New insights from three trilemma leadership. Energy, 248, p.123619.

[25] Hedden, S., Moyer, J.D. and Rettig, J., 2013. Fracking for shale gas in South Africa: blessing or curse?. Institute for Security Studies Papers, 2013(9), p.12.

[26] Stephenson, E. and Shaw, K., 2013. A dilemma of abundance: Governance challenges of reconciling shale gas development and climate change mitigation. Sustainability, 5(5), pp.2210-2232.

[27] Sever, S.D., 2022. Natural Gas and Energy Security. The Palgrave Handbook of Natural Gas and Global Energy Transitions, pp.97-120.

[28] Prado-Lopez, V., Stewart, T., Makowski, M. and von Winterfeldt, D., 2013. Value measurement analysis of energy tradeoffs in South Africa. Proc. ISSST, v1.

[29] Clark, S., McGregor, C. and van Niekerk, J.L., 2022. Using liquefied petroleum gas to reduce the operating cost of the Ankerlig peaking power plant in South Africa. Journal of Energy in Southern Africa, 33(2), pp.15-23.

[30] Xie, L., Hu, X., Zhang, X. and Zhang, X.B., 2022. Who suffers from energy poverty in household energy transition? Evidence from clean heating program in rural China. Energy Economics, 106, p.105795.

[31] Beidari, M., Lin, S.J. and Lewis, C., 2017. Decomposition analysis of CO2 emissions from coal-sourced electricity production in South Africa. Aerosol and Air Quality Research, 17(4), pp.1043-1051.

[32] Makgetla, N., 2021. Governance and the Just Transition. Trade & Industrial" Policy Strategies (TIPS), 24.

[33] Nhamo, G., 2013. Green economy readiness in South Africa: A focus on the national sphere of government. International Journal of African Renaissance Studies-Multi-, Inter-and Transdisciplinarity, 8(1), pp.115-142..

[34] Hanto, J., Krawielicki, L., Krumm, A., Moskalenko, N., Löffler, K., Hauenstein, C. and Oei, P.Y., 2021. Effects of decarbonization on the energy system and related employment effects in South Africa. Environmental Science & Policy, 124, pp.73-84.

[35] Voumik, L.C. and Sultana, T., 2022. Impact of urbanization, industrialization, electrification and renewable energy on the environment in BRICS: fresh evidence from novel CS-ARDL model. Heliyon, 8(11), p.e11457.

[36] IEA, 2020. Report on South Africa. Available from https://www.iea.org/countries/south-africa. [Retrieved on 05th March, 2023].

[37] Jin, Y., Andersson, H. and Zhang, S., 2017. China's Cap on Coal and the Efficiency of Local Interventions: A Benefit-Cost Analysis of Phasing out Coal in Power Plants and in Households in Beijing1. Journal of Benefit-Cost Analysis, 8(2), pp.147-186.

[38] Cai, B., Li, T., Wang, K., Li, Z., Zhu, L., Wen, J. and Xue, Y., 2021, December. Impact of Generation Companies' Heterogeneous Investment Behaviors on the Effects of Non-fossil Energy Incentive Policies. In 2021 IEEE Sustainable Power and Energy Conference (iSPEC) (pp. 2295-2300). IEEE.

[39] Gonzalez-Salazar, M.A., Kirsten, T. and Prchlik, L., 2018. Review of the operational flexibility and emissions of gas-and coal-fired power plants in a future with growing renewables. Renewable and Sustainable Energy Reviews, 82, pp.1497-1513.

[40] Luo, S., Hu, W., Liu, W., Xu, X., Huang, Q., Chen, Z. and Lund, H., 2021. Transition pathways towards a deep decarbonization energy system—A case study in Sichuan, China. Applied Energy, 302, p.117507.

[41] Scholes, B., Lochner, P.A., Schreiner, G. and De Jager, M., 2016. Shale gas development in the Central Karoo: A scientific assessment of the opportunities and risks.

[42] Andreasson, S., 2018. The bubble that got away? Prospects for shale gas development in South Africa. The Extractive Industries and Society, 5(4), pp.453-460.

[43] Putter, A., 2018. Natural Gas in Southern Africa, Part 2: Available gas resources and future development. Available https://www.ownerteamconsult.com/natural-gas-in-southern-africa-part-2-available-gas-resources-and-future-development/. Accessed 20th Dec, 2022.

[44] Williams, L. and Sovacool, B.K., 2019. The discursive politics of 'fracking': Frames, storylines, and the anticipatory contestation of shale gas development in the United Kingdom. Global environmental change, 58, p.101935.

[45] Zanocco, C., Boudet, H., Clarke, C.E., Stedman, R. and Evensen, D., 2020. NIMBY, YIMBY, or something else? Geographies of public perceptions of shale gas development in the Marcellus Shale. Environmental Research Letters, 15(7), p.074039.

[46] Tan, H., Wong-Parodi, G. and Xu, J., 2020. Not under my backyard? Psychological distance, local acceptance, and shale gas development in China. Energy Research & Social Science, 61, p.101336.

[47] Irene, J.O., 2021. The socio-economic and environmental implications of shale gas development in the Karoo, South Africa (Doctoral dissertation, Kingston University).

[48] Whitton, J. and Charnley-Parry, I., 2018. Shale gas governance in the United States, the United Kingdom and Europe: Public participation and the role of social justice. In Governing Shale Gas (pp. 213-226). Routledge.

[49] Gregory, J. and Sovacool, B.K., 2019. The financial risks and barriers to electricity infrastructure in Kenya, Tanzania, and Mozambique: A critical and systematic review of the academic literature. Energy policy, 125, pp.145-153.

[50] Bischof-Niemz, T. and Creamer, T., 2018. South Africa's energy transition: A roadmap to a decarbonised, low-cost and job-rich future. Routledge.

[51] Todd, I. and McCauley, D., 2021. Assessing policy barriers to the energy transition in South Africa. Energy Policy, 158, p.112529.

[52] Ross, K. and Winkler, H., 2021. Effective tracking of nationally determined contributions: A case study on South Africa. Journal of Energy in Southern Africa, 32(2), pp.11-25.

[53] RSA [Government of the Republic of South Africa] 2015. South Africa's Intended Nationally Determined Contribution (INDC). Pretoria: Government of the Republic of South Africa.https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/South%20Africa%20First/South%20Africa.pdf. Accessed 20th December, 2022.

[54] Boersma, T. and Johnson, C., 2012. The shale gas revolution: US and EU policy and research agendas. Review of Policy Research, 29(4), pp.570-576.

[55] Thomas, M., Pidgeon, N., Evensen, D., Partridge, T., Hasell, A., Enders, C., Herr Harthorn, B. and Bradshaw, M., 2017. Public perceptions of hydraulic fracturing for shale gas and oil in the United States and Canada. Wiley Interdisciplinary Reviews: Climate Change, 8(3), p.e450.

[56] Weber, C.L. and Clavin, C., 2012. Life cycle carbon footprint of shale gas: Review of evidence and implications. Environmental science & technology, 46(11), pp.5688-5695.

[57] Jiang, M., Griffin, W.M., Hendrickson, C., Jaramillo, P., VanBriesen, J. and Venkatesh, A., 2011. Life cycle greenhouse gas emissions of Marcellus shale gas. Environmental Research Letters, 6(3), p.034014.

[58] Nichols, C. and Victor, N., 2015. Examining the relationship between shale gas production and carbon capture and storage under CO2 taxes based on the social cost of carbon. Energy Strategy Reviews, 7, pp.39-54.

[59] Li, H., Lau, H.C., Wei, X. and Liu, S., 2021. CO2 storage potential in major oil and gas reservoirs in the northern South China Sea. International Journal of Greenhouse Gas Control, 108, p.103328.

[60] Shirbazo, A., Taghavinejad, A. and Bagheri, S., 2021. CO2 Capture and Storage Performance Simulation in Depleted Shale Gas Reservoirs as Sustainable Carbon Resources. Journal of Construction Materials, pp.1-18.

[61] Lawrence, T.B. and Suddaby, R., 2006. 1.6 institutions and institutional work. The Sage handbook of organization studies, pp.215-254.

[62] Kivimaa, P. and Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Research policy, 45(1), pp.205-217.

[63] Yang, K., Schot, J. and Truffer, B., 2022. Shaping the directionality of sustainability transitions: the diverging development patterns of solar photovoltaics in two Chinese provinces. Regional Studies, 56(5), pp.751-769.

[64] Geels, F.W., 2014. Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective. Theory, culture & society, 31(5), pp.21-40.

[65] Ting, M.B. and Byrne, R., 2020. Eskom and the rise of renewables: Regime-resistance, crisis and the strategy of incumbency in South Africa's electricity system. Energy Research & Social Science, 60, p.101333.

[66] Fünfschilling, L., 2014. A dynamic model of socio-technical change: Institutions, actors and technologies in interaction (Doctoral dissertation, University_of_Basel).

[67] Binz, C., Truffer, B. and Coenen, L., 2016. Path creation as a process of resource alignment and anchoring: Industry formation for on-site water recycling in Beijing. Economic Geography, 92(2), pp.172-200.

[68] Ghosh, B. and Schot, J., 2019. Towards a novel regime change framework: Studying mobility transitions in public transport regimes in an Indian megacity. Energy Research & Social Science, 51, pp.82-95.

[69] Coenen, L., Benneworth, P. and Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Research policy, 41(6), pp.968-979.

[70] Geels, F.W., 2012. A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. Journal of transport geography, 24, pp.471-482.

[71] Truffer, B. and Coenen, L., 2012. Environmental innovation and sustainability transitions in regional studies. Regional studies, 46(1), pp.1-21.

[72] Hansen, T. and Coenen, L., 2015. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. Environmental innovation and societal transitions, 17, pp.92-109.

[73] Truffer, B., Murphy, J.T. and Raven, R., 2015. The geography of sustainability transitions: Contours of an emerging theme. Environmental Innovation and Societal Transitions, 17, pp.63-72.

[74] Wittmayer, J.M., Schäpke, N., van Steenbergen, F. and Omann, I., 2014. Making sense of sustainability transitions locally: how action research contributes to addressing societal challenges. Critical policy studies, 8(4), pp.465-485.

[75] Holtz, G., Alkemade, F., De Haan, F., Köhler, J., Trutnevyte, E., Luthe, T., Halbe, J., Papachristos, G., Chappin, E., Kwakkel, J. and Ruutu, S., 2015. Prospects of modelling societal transitions: Position paper of an emerging community. Environmental Innovation and Societal Transitions, 17, pp.41-58.

[76] Haxeltine, A., Whitmarsh, L., Bergman, N., Rotmans, J., Schilperoord, M. and Kohler, J., 2008. A conceptual framework for transition modelling. International journal of innovation and sustainable development, 3(1-2), pp.93-114.

[77] Geels, F.W. and Schot, J., 2007. Typology of sociotechnical transition pathways. Research policy, 36(3), pp.399-417.

[78] Sydow, J., Lerch, F. and Staber, U., 2010. Planning for path dependence? The case of a network in the Berlin-Brandenburg optics cluster. Economic Geography, 86(2), pp.173-195.

[79] van den Hoed, R. and Vergragt, P.J., 2004. Institutional change in the automotive industry: or how fuel cell technology is being institutionalised. Greener Management International, (47), pp.45-61.

[80] Elzen, B., Geels, F.W. and Green, K. eds., 2004. System innovation and the transition to sustainability: theory, evidence and policy. Edward Elgar Publishing.

[81] Grin, J., Rotmans, J. and Schot, J., 2010. Transitions to sustainable development: new directions in the study of long term transformative change. Routledge.

[82] Rosenbloom, D., 2017. Pathways: An emerging concept for the theory and governance of low-carbon transitions. Global Environmental Change, 43, pp.37-50.

[83] Borghei, B.B., 2018. Incumbent Actors in Sectoral Transformations Towards Sustainability: A sociotechnical study of the European heavy commercial vehicles sector (Doctoral dissertation, Linköping University Electronic Press).

[84] Sovacool, B.K., Kester, J., Noel, L. and de Rubens, G.Z., 2020. Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review. Renewable and Sustainable Energy Reviews, 131, p.109963.

[85] Willig, C., 2001. Qualitative research in psychology: A practical guide to theory and method. Buckingham: OUP.

[86] Siddiqui, S. and Qamar, A.H., 2021. Risk perception and protective behavior in the context of COVID-19: a qualitative exploration. Asian bioethics review, 13(4), pp.401-420.

[87] Ryan, G.W. and Bernard, H.R., 2003. Techniques to identify themes. Field methods, 15(1), pp.85-109.

[88] Tansey, O., 2009. Process tracing and elite interviewing: a case for non-probability sampling. Methoden der vergleichenden Politik-und Sozialwissenschaft: Neue entwicklungen und anwendungen, pp.481-496.

[89] Batanero, C., 2015, February. Understanding randomness: challenges for research and teaching. In CERME 9-ninth congress of the European Society for Research in Mathematics Education (pp. 34-49).

[90] Zheng, L., Miao, M., Lim, J., Li, M., Nie, S. and Zhang, X., 2020. Is lockdown bad for social anxiety in COVID-19 regions?: A national study in the SOR perspective. International journal of environmental research and public health, 17(12), p.4561.

[91] DoE, 2011. Electricity Regulation Act No.4 of 2006. Electricity Regulations on the Integrated Resource Plan 2010-2030. Government Gazette 34263 No. 9531, vol. 551. https://www.energy.gov.za/irp/2010/irp2010.pdf accessed 16th May, 2023.

[92] Cilliers, J., 2021. The Future of Africa: Challenges and Opportunities (p. 421). Springer Nature.

[93] Renn, O. and Benighaus, C., 2013. Perception of technological risk: insights from research and lessons for risk communication and management. Journal of Risk Research, 16(3-4), pp.293-313.

[94] Tan, H., Wong-Parodi, G., Zhang, S. and Xu, J., 2022. Public risk perceptions of shale gas development: A comprehensive review. Energy Research & Social Science, 89, p.102548.

[95] Savadori, L., Savio, S., Nicotra, E., Rumiati, R., Finucane, M. and Slovic, P., 2004. Expert and public perception of risk from biotechnology. Risk Analysis: An International Journal, 24(5), pp.1289-1299.

[96] Dobbie, M.F. and Brown, R.R., 2014. A framework for understanding risk perception, explored from the perspective of the water practitioner. Risk analysis, 34(2), pp.294-308.

[97] Van der Linden, S., 2017. Determinants and measurement of climate change risk perception, worry, and concern. The Oxford Encyclopedia of Climate Change Communication. Oxford University Press, Oxford, UK.

[98] Leiserowitz, A., 2006. Climate change risk perception and policy preferences: The role of affect, imagery, and values. Climatic change, 77(1-2), pp.45-72.

[99] Gierlach, E., Belsher, B.E. and Beutler, L.E., 2010. Cross-cultural differences in risk perceptions of disasters. Risk Analysis: An International Journal, 30(10), pp.1539-1549.

[100] Stirling, A. and Gee, D., 2002. Science, precaution, and practice. Public health reports, 117(6), p.521.

[101] Besley, J.C. and Nisbet, M., 2013. How scientists view the public, the media and the political process. Public understanding of science, 22(6), pp.644-659.

[102] Landström, C., Hauxwell-Baldwin, R., Lorenzoni, I. and Rogers-Hayden, T., 2015. The (mis) understanding of scientific uncertainty? How experts view policy-makers, the media and publics. Science as Culture, 24(3), pp.276-298.

[103] Bellani, J., Verma, H.K., Khatri, D., Makwana, D. and Shah, M., 2021. Shale gas: a step toward sustainable energy future. Journal of Petroleum Exploration and Production Technology, 11, pp.2127-2141.

[104] Burbidge, M.K. and Adams, C.A., 2020. An assessment of social and environmental impacts of a new shale gas industry in the Vale of Pickering, North Yorkshire. Local Environment, 25(7), pp.492-511.

[105] Lindner, R., Daimer, S., Beckert, B., Heyen, N., Koehler, J., Teufel, B., Warnke, P. and Wydra, S., 2016. Addressing directionality: Orientation failure and the systems of innovation heuristic. Towards reflexive governance (No. 52). Fraunhofer ISI Discussion Papers-Innovation Systems and Policy Analysis.

[106] Mazzucato, M., 2018. Mission-oriented research & innovation in the European Union. European Commission.

[107] Mylan, J., Morris, C., Beech, E. and Geels, F.W., 2019. Rage against the regime: Niche-regime interactions in the societal embedding of plant-based milk. Environmental Innovation and Societal Transitions, 31, pp.233-247.

[108] Tsarev, D., Trofimova, A., Alodjants, A. and Khrennikov, A., 2019. Phase transitions, collective emotions and decision-making problem in heterogeneous social systems. Scientific reports, 9(1), pp.1-13.

[109]Yesterday, N., 2012. Organization change and development: In practice and in theory. Handbook of psychology, industrial and organizational psychology, 12, p.390.

[110] Rotmans, J., Loorbach, D. and Kemp, R., 2016. Complexity and transition management. In Complexity and planning (pp. 195-216). Routledge.

[111] Slee, B., 2020. Fossil fuel decline and the rural economy: the case of Scotland. In The Palgrave Handbook of Managing Fossil Fuels and Energy Transitions (pp. 371-401). Palgrave Macmillan, Cham.