

https://dspace.org/

Water-energy and climate change nexus in South Africa: application of the integrated water resource management approach for sustainable development

Mathetsa, Steven Matome

2020
https://hdl.handle.net/10539/30156

Downloaded from a DSpace repository. https://dspace.org/



WATER-ENERGY AND CLIMATE CHANGE NEXUS IN SOUTH AFRICA: APPLICATION OF THE INTEGRATED WATER RESOURCE MANAGEMENT APPROACH FOR SUSTAINABLE DEVELOPMENT

By

STEVEN MATOME MATHETSA

THESIS
Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

UNIVERSITY OF THE WITWATERSRAND

GEOGRAPHY AND ENVIRONMENTAL STUDIES

School of Geography, Archaeology, and Environmental Studies

SUPERVISOR: Professor Mulala Danny Simatele

CO-SUPERVISOR: Professor Isaac T. Rampedi

ETHICS CLEARANCE PROTOCOL NUMBER: H17/11/31

DECLARATION 1-PLAGIARISM

I, Steven Matome Mathetsa, declare that "**Water-energy and climate change nexus in South Africa: application of the integrated water resource management approach for sustainable development**" is my original work and that all the sources that I have used or quoted have been indicated and acknowledged using complete references. The thesis is being submitted for the award of the degree of Doctor of Philosophy (PhD.) to the Faculty of Science, School of Geography, Archaeology and Environmental Studies (GAES) at the University of the Witwatersrand, Johannesburg, South Africa. I further declare that I have not previously submitted this work, or part of it, for examination at the University of the Witwatersrand for another qualification or any other higher education institution.

DECLARATION 2: PUBLICATIONS

I, Steven Matome Mathetsa, declare that I undertook all the data collection, analysis, development and writing of the manuscripts and articles mentioned below. Sections of this work have been published or submitted as manuscripts for publication to the following peer-reviewed journals.

1. Mathetsa, S.M., Simatele, M.D., Rampedi, I.T. and Gericke, G. 2019. Perspectives on integrated water resource management and its relevance in understanding the water-energy-climate change nexus in South Africa. **Journal of Energy in Southern Africa**. Vol. 30, No. 3. 11-21. **DOI**: https://doi.org/10.17159/2413-3051/2019/v30i3a5654 (Published). **FREE ACCESS**: https://journals.assaf.org.za/index.php/jesa/article/view/5654

2. Mathetsa, S.M., Simatele, M.D., Rampedi I.T. and Gericke, G. 2019. Assessing Water-Energy-Climate Change Nexus in South Africa: Towards water as a finite resource. **Development Southern Africa**. (Peer Review-Second draft).

3. Mathetsa, S.M., Simatele, M.D., Rampedi, I.T. and Gericke, G. 2019. Application of participatory approach as an analytical framework for Water-Energy-Climate Change nexus in South Africa. **International Journal of Environment and Sustainable Development** (Peer Review-First draft).

Steven Matome Mathetsa Signature Date: 14 April 2020

As the candidate's supervisor (s), I/we certify the above statement and have approved this thesis submission. I/we certify that the above statement is correct.

Prof. Mulala Danny Simatele Signature Date: 14 April 2020

Prof. Isaac T. Rampedi Signature Date: 14 April 2020

DEDICATION

To God Almighty, thank you for the wisdom and opportunity to carry out this project.

And

A special dedication to my parents for the foundation they laid since my birth. This project would not have been accomplished if it hasn't been for their teaching and words of inspiration.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Eskom SoC (Ltd) for the financial support accorded to me during the study. While this study was made possible by the role of several people, special mention is given to the following:

Firstly, special thanks and gratitude to my study supervisor and leader, Prof. Mulala Danny Simatele for the valuable guidance and knowledge shared throughout this study. Despite all the trials presented to us during this study, your determination, inspiration, encouragement, constructive criticism, and insights remained incredible. You provided hope where none existed. Your father-figure role and collaboration during this process will forever be endured. Likewise, to my co-supervisor, Prof. Isaac Tebogo Rampedi, this is the third project that we are collaborating on. You are forever present on my side and provided valuable knowledge throughout. Thank you for the valuable input on this project. To both Professors, thank you for the knowledge and skills that you have shared, thus improving my personal and professional life.

I would like to extend my warm gratitude to Dr Gerhard Gericke for the meaningful contribution you have made in this project, particularly during the formulation of the study project and provision of key insights. Also, I would like to thank the entire Eskom community who supported me throughout this study, particularly Subhas Maharaj and Jenny Reeves for allowing me to carry out this project.

I would like to acknowledge the unwavering support and motivation that I received from my friends and colleagues to complete this project successfully. Similarly, I am thankful to all the experts, stakeholders and organisations who afforded me time to share their knowledge, perspectives, and data about this study.

Lastly and most importantly, special thanks to my family who, in different ways, have been there for me. My wife and kids, in particular, you guys have missed my company when my attention was mainly on this research. For that, I want to say thank you for your patience, understanding and unwavering support during my study.

ABSTRACT

The influence of resources such as water, energy, land, and food on each other has encouraged global communities to investigate their role in the sustainable development discourse and develop contemporary measures to address interlinkages between these systems. The need to develop these measures is prompted by the implications of these interactions on several Sustainable Development Goals (SDGs), particularly those linked to the supply of these resources. Recent developments suggest that the emergence of climate change insinuates the overarching role that this phenomenon has on the already constrained supply of resources such as water and energy. The inextricable interlinkage of climate change with water and energy resources results in what is commonly known as Water-Energy-Climate Change (WECC) nexus. This nexus has, however, not been extensively investigated particularly in the poor and middle-income countries such as those in the Sub-Saharan Africa Region. In the context of South Africa, it is argued that the WECC occurrence is aggravated by the overreliance of water-intensive and greenhouse gas-emitting coal-fired power stations in the country's energy generating systems. This is despite the semi-aridity of the country which limits its freshwater availability for various socio-economic activities. Existing literature which has dealt with issues relating to the WECC nexus suggests that each of the WECC components is a threat to South Africa's socio-economic development, as well as ecosystem wellbeing. This, therefore, requires an urgent need to identify and develop appropriate holistic strategies and policies to coordinate the management of the WECC nexus in ways that will contribute to the formulation of systematic approaches directed at building the adaptive capacity and resilience of all the sub-sectors of the economy. Although there are now efforts targeted at understanding these coupled interactions, existing arguments suggest that there is a lack of integrated approach through which policy development processes intended at minimizing the negative impacts of the WECC can be pursued. This deficit has been propagated and sustained by the continued application of the silo or sectoral approach in the management of the WECC nexus. Thus, the current state of affairs requires the adoption of holistic and system thinking approaches, and the promotion of increased collaboration among different stakeholders mandated to manage water and energy resources with climate change as a common challenge across all subsectors of the economy. The current study, therefore, seeks to understand and explore the WECC nexus in South Africa, with the view to promote a holistic and coordinated approach in its analysis. This is done within the discourse of the Integrated Water Resource Management (IWRM)

framework, which was found to be effective in the sustainable management of water resources. The selection of this framework is persuaded by the centric role that water plays in the socio-economic development and ecological activities of the country, particularly the energy sector.

The study selectively applied the IWRMs' principles of "water as a finite resource" and "public participatory approach" to obtain the empirical evidence used to verify and validate the extent to which this nexus is understood in South Africa. Although the empirical evidence was obtained from different sectors and key stakeholders across the country, the Waterberg and Highveld regions were purposefully used as case study areas. Three basic criteria were taken into consideration in selecting these areas and relevant stakeholders appropriately. Firstly, the role that these regions play in the provision of the country's energy and water resources was considered. This was motivated by varying climatic conditions coupled with the presence of resources such as coal and water in these catchments. Secondly, the ability of the existing water availability in these catchments to provide a meaningful comparison in response to erratic climate conditions and usage within the energy sector. It is argued that the water usage and availability in these catchments are driven by climate-related conditions such as temperature, drought, and floods; as well as demand from the energy sector. And lastly, the prominent role that different stakeholders from the sectors of water, energy and climate change play in promoting coordinated and collaborated efforts to manage this nexus effectively. This was motivated by varying perceptions provided by different research participants on several issues such as the lack of integrated planning and policy development across these three sectors.

The selected principles of IWRM allowed for multiple methodological approaches to be undertaken in this study. Firstly, a quantitative approach was used to verify the selected converse interdependences between water, energy and climate change. For instance, the water-energy interlinkage was verified through the amount of water used to produce electricity for power stations located at the selected study areas. This approach was driven by the role that water resources play not only in the energy but other sub-sectors of the economy, despite being a limited resource in the country. Secondly, in applying the qualitative approach, several research techniques were used to assess the suitability of a participatory approach to comprehend the WECC nexus and suitability of current measures in South Africa. For example, a participatory observation was used to assess the extent to which coordination and collaboration practices are applied in the management of WECC. Also, the two approaches

were corroborated by the literature appraisal, through which, the extent to which WECC has been investigated locally and across international communities was verified.

The empirical evidence from this study suggests that the interlinkage between the systems of water, energy and climate change is inevitable in South Africa. This is demonstrated by the bio-physical data which conversely links interactions of the elements of water, energy and climate change. Moreover, the results of the study disclosed that similar to most communities around the globe, South Africa is still lagging in research and development of policies aimed at holistically managing the WECC. These remarks are made despite the key role that policy play in driving efficiencies in resource management and usage. This study further reveals that the prevailing fragmented policy planning and development is exacerbated by a limited understanding and minimal stakeholder consultation among key stakeholders in the water, energy and climate change sectors. Also, the evidence from this study suggests that considerations of WECC management from the water-centric theme are profound. This view is encouraged by the country's depleting water resources which, despite being central towards essential socio-economic factors such as energy and food, are deeply affected by climate variabilities. Lastly, it is argued in this study that participatory approaches play a key role in assessing complex and multisector systems such as WECC. This study, therefore, recommends that an effective stakeholder engagement which will result in a collaborative and coordinated decision-making process should be promoted in the country. One of the most pivotal implications from this participatory approach is that an informed, inclusive and integrated policy development that is integrated across water, energy and climate change sectors is an absolute imperative for South Africa.

The findings from this study make several contributions to the body of knowledge in sustainable development. *Firstly*, they provide an improved understanding and awareness of WECC in South Africa. This also proposes the utilisation of IWRM as one of the contemporary measures suitable for capturing the risks and opportunities emanating from this nexus. This contribution is relevant for promoting resource efficiency in the country, given the growing concerns over water and energy demand and supply. *Secondly*, the study raises the importance of both physical and social data in the decision-making phases of WECC. This argument calls for the establishment of contemporary measures which will ensure that there is an establishment of data handling, management, and accessibility systems intended at promoting informed decision-making processes. *Thirdly*, an integrated approach, particularly from the

planning, policy development, and implementation perspective is essential in addressing complex systems such as WECC nexus. This finding is essential considering varying roles that each sector plays in sustainable and national developmental endeavours. Given these contributions, it can be concluded that the IWRM approach can be a vehicle through which the risks and opportunities associated with WECC can be driven and managed in South Africa to support the achievement of associated SGDs and national developmental objectives.

Key Words: Energy, Climate Change; South Africa, Nexus, Sustainable Development, Integrated Water Resource Management

Table of Contents

Contents

DECLARATION 1-PLAGIARISM i

DECLARATION 2: PUBLICATIONS ii

DEDICATION iii

ACKNOWLEDGEMENT iv

ABSTRACT v

LIST OF TABLES xi

LIST OF FIGURES xi

LIST OF ABBREVIATIONS AND ACRONYMS xii

CHAPTER ONE 1

FRAME OF REFERENCE 1

1.1. Background to the study 1

1.2. Thematic Considerations 3

1.3. Research Questions 4

1.4. Research aim and objectives 5

1.5. Significance of the study 5

1.7. Research Design 10

1.7.1. Research philosophy 10

1.7.2. Methodological approach 11

1.7.3. Study Area 12

1.8. Scope of the study 15

1.8.1. Ethical considerations 15

1.9. Structure of the study 15

CHAPTER TWO 17

ABSTRACT 17

2.1. Introduction 18

2.2. Methodology 20

2.3. Results and Discussion 21

2.3.1. Contextual developments on WECC nexus 21

2.3.2. Governance of the WECC nexus 25

2.3.3. Towards the integrated approach 27

2.4. Conclusions 29

CHAPTER 3 31

ABSTRACT 31
3.1. Introduction 32
3.2. The significance of the IWRM Framework towards the WECC nexus 35
3.2.1. Water is a finite resource in the South African context 36
3.3. Methodological approach 37
3.4. Results and discussions 39
3.4.1. Coupled water-energy interchange 39
3.4.2. The energy sectors' contribution to GHG emissions 42
3.4.3. Influence of climate change on water resources 43
3.5. Conclusions and recommendations 44
CHAPTER FOUR 46
ABSTRACT 46
4.1. Introduction 46
4.2. An appraisal of the upsurge of the participatory approach as a decision-making tool 48
4.2.1. Towards a participatory approach in the management of WECC nexus 50
4.3. Methodological consideration 52
4.4. Results and Discussions 55
4.4.1. Key stakeholders' perceptions of WECC in South Africa 55
4.4.2. Collaboration and coordination as a means to implement WECC in South Africa 58
4.4.3. Perceptions of the research participants on the policy development on WECC in South Africa 62
4.4. Conclusions 64
CHAPTER FIVE 66
CONCLUSIONS AND RECOMMENDATIONS 66
5.1. Overview of the key findings of the study 66
5.2. Key recommendations 68
5.3. Recommendations for future research 70
REFERENCES 71
APPENDIX 84
A. ETHICS CLEARANCE CERTIFICATE 84
B. PARTICIPANTS INFORMATION SHEET (INTERVIEW) 85
C. PARTICIPANTS INFORMATION SHEET (FOCUS GROUP DISCUSSION) 86
D. PARTICIPANTS INFORMATION SHEET (PARTICIPANTS OBSERVATION) 87
E. CONSENT FORM (INTERVIEW) 88

F. CONSENT FORM (FOCUS GROUP DISCUSSION) 89
G. CONSENT FORM (PARTICIPANTS OBSERVATION) 90
H. QUESTIONNAIRE 91
I. PUBLISHED ARTICLE 1 95

LIST OF TABLES

Table 1.1: Summary of methods used to attain the study objectives 12
Table 1.2: Summary of chapters 16
Table 3.1: Sources of raw data 38
Table 4.1: Profile of research respondents 54
Table 4.2: Perceptions of the research participants on WECC nexus in South Africa 56
Table 4.3: Views on the coordination and collaboration of WECC among research participants in South Africa 59
Table 4.4: Perceptions of research participants on policy development in South Africa 62

LIST OF FIGURES

Figure 1.1: Water allocations for various socio-economic sectors in South Africa 8
Figure 1.2: The general framework for IWRM 10
Figure 1.3: Geographical location of the Highveld region 14
Figure 1.4: Geographical location of the Waterberg region 14
Figure 2.1: Coupled interactions between water, energy and climate change in South Africa. 25
Figure 3.1: Water used per Kilowatt per hour Sent Out for the Highveld and Waterberg stations 40
Figure 3.2: Relative CO_2 and N_2O produced during electricity generation 42
Figure 3.3: Comparison of the temperature and rainfall interactions 44

LIST OF ABBREVIATIONS AND ACRONYMS

COST	European Cooperation in Science and Technology
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry, and Fishery
DMRE	Department of Mineral Resources and Energy
DoE	Department of Energy
DWS	Department of Water and Sanitation
GT	Grounded Theory
GWP	Global Water Partnership
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
IWRM	Integrated Water Resource Management
NCCRP	National Climate Change Response Policy
NDP	National Developmental Plans
NWA	National Water Act
NWRS	National Water Resource Strategy
PA	Participatory Approach
REIPP	Renewable Energy Independent Power Producers
SAWS	South African Weather Services
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
UN	United Nations
WECC	Water-Energy-Climate Change
WEF	Water-Energy-Food
WRC	Water Research Commission

CHAPTER ONE

FRAME OF REFERENCE

1.1. Background to the study

The decline in the earth's carrying capacity has persuaded communities around the world to adopt the sustainable development concept, which aims at promoting the attainment of socio-economic growth without compromising ecological needs (United Nations [UN], 1972; UN, 1992]. This concept intends to improve the usage of natural resources such as water, biodiversity, atmosphere, and land effectively in addressing the socio-economic welfare while maintaining their protection against degradation. Despite this call for sustainable development, human beings are confronted with a challenge to address a set of complex and interrelated issues that are poised to cause insecurities in the supply of resources. For example, the rapid population growth around the globe has immensely put pressure on the supply of critical yet interdependent resources such as food, water, and energy. This resulted in the formulation of Sustainable Development Goals (SDGs) which aim at meeting the needs of the present generations without compromising those of the future (UN, 2002].

One of the key features of SDGs is the increasing need to recognize water and energy supply as one of the fundamental necessities of modern life (Hussey and Pittock, 2012; Carpenter, 2015). Despite their significant role in sustaining socio-economic needs, these systems are conversely connected in a concept known as Water-Energy (WE) nexus (Scott et al., 2011; Siddiqi and Anadon, 2011; Mabhaudhi et al., 2016). The connection between these two resources is demonstrated through the role that energy plays in the water value chains (abstraction, treatment and distributed) and visa-versa, the dependence of various energy generating systems such as nuclear, coal-combustion and hydropower on freshwater. Recent developments suggest that the inevitable occurrence of climate change and its implications on these water and energy resources poses the risks towards their supply (Mukheibir, 2008; Cammerman, 2009; Liu, et al., 2017). The converse interdependence of water and energy, and taking climate change as a common challenge across all subsectors of the economy, results in a complex configuration termed the Water-Energy-Climate Change (WECC) nexus. The existence of this nexus does, however, result in wider societal challenges associated with the

sustainable supply of key resources such as energy and food. For instance, Pittock et al. (2015) are of the view that the drought between the years 2000 to 2007, which resulted from high temperatures, reduced several countries' water supply, and therefore, increased their energy needed for water distribution. Contrariwise, the observed rise in energy demand resulted in increased concentrations of greenhouse gas emissions which intensify climate variabilities thus affecting water availability (Pittock et al. 2015). In Sub-Saharan Africa (SSA), these challenges are at their highest level and hinder the socio-economic development goals of communities in this region (Prasad et al. 2012). This is aggravated by the region's over-dependence on hydropower for their energy generation. In Kenya for instance, drought-driven water shortages disrupted the country's energy production and supply over the last few decades (Prasad et al., 2012). In the Southern African region, the water availability for energy generation is complicated by the shared water basins where upstream water usage activities affect downstream ones (Mabhaudhi et al., 2016). These observations support the views of Cammerman (2009), who argued that countries experiencing water limitations exacerbated by climate variabilities while their energy demands are rising could face severe limitations in attaining their SDGs.

In the context of South Africa, increasing population growth, industrialisation and urbanisation are rapidly increasing the demand for resources such as food, freshwater, and energy (Department of Water and Sanitation [DWS], 2013). It is, however, the freshwater limitations that cause great concern for the country. These concerns are intensified by the role that water plays across all sub-sectors of the economy particularly agriculture and energy. For instance, it is indicated that 67% of the freshwater in the country is allocated to irrigation activities while the power production sector is guaranteed approximately 2% (DWS, 2013). The country's freshwater limitations, aggravated by climate change, encourage the country to promote sustainable management of its water resources to develop resilient systems to sustain socio-economic and ecological activities such as energy and food production.

The above deliberations seem to suggest that the management of complex systems such as WECC can be centralised around sustainable management of water resources (Cammerman, 2009; Head and Cammerman, 2010). Based on this observation, it would not be an exaggeration to argue that the dire water situation in the country prompts the management of WECC from a water-centric perspective. In light of this suggestion, one of the tools regarded as vital in sustainably managing water resources is the Integrated Water Resource Management

(IWRM) framework (Pollard and Du Toit, 2008; Leendertse et al. 2008) which could be relevant to address the WECC. This approach is defined as a process that seeks to promote the coordinated development and management of water, land and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Global Water Partnership [GWP], 2000; Bindra et al., 2013). By nature of its definition, implementation of the IWRM involves a holistic view of water-related resources such as land use and users' identification, understanding flow regimes, coordination of institutional arrangement and socio-economic interactions within a particular catchment. Aligned with the IWRM's objective to enhance the management of water resources in a risk-based approach, this study, therefore, assesses this framework's role in understanding the risks and opportunities emanating from this nexus.

1.2. Thematic Considerations

This study is motivated by emerging socio-economic development endeavours in the country, which heavily rely on water and energy resources that are prone to climate change impacts. Secondly, it has emerged that water constraints in the country are one of the most critical factors threatening other key subsectors of the economy (Walmsley et al., 2001; Mathetsa et al., 2016). In the context of this study, it is argued that sustainable water resource management is of importance in the promotion of the understanding, integration, and governance of nexus systems such as WECC (Cammerman, 2009). This is motivated by observations that the nexus elements are not managed in an integrated manner thus putting SGDs at risk of not being achieved (Mabhaudhi et al., 2016; Nhamo et al., 2018). In the context of South Africa, the socio-economic endeavours such as poverty alleviation, health systems, food production, and job creation are dependent on water availability. However, the limited freshwater availability aggravated by deteriorating water quality, below-average mean annual precipitation of 500 mm, and semi-aridity geographical location results in disruptions of socio-economic related development in the country. Furthermore, the country is regarded as a climate-change hotspot, thus affecting freshwater availability negatively (DWS, 2013; Intergovernmental Panel on Climate Change [IPCC], 2007, Water Research Commission [WRC], 2017). These climate variabilities account for water-reducing activities such as increased temperature and evaporation rates, floods, droughts, deteriorating water quality as a result of high salt contents emanating from key activities such as mining and agriculture, and compromised infrastructure due to ageing and poorly managed systems. For instance, it is predicted that the country will undergo water shortages of approximately 234 gigalitres as early as 2025 (Mukheibir, 2008;

WRC, 2015). The observation suggests that the prolonging water shortages in the country are expected to continue thus limiting the productivity of water-reliant sectors such as agriculture, households (urban and rural) and energy supply.

Drawing from these deliberations, it is argued that South Africa's power generation sector is one of the areas that will be significantly affected by water shortages. This is due to the country's greater proportion of its electricity being produced from the coal-fired power stations which, despite emitting greenhouse gases that potentially accelerate climate change and consumes high water volumes (Singleton, 2010; Eskom, 2016). Furthermore, the majority of these coal-fired power stations are situated in catchments such as the Waterberg and Highveld, which are already experiencing constrained freshwater availability (Pather, 2004; Mukheibir, 2008). These freshwater constraints have already resulted in projects to augment water availability for power generation and other key economic sectors such as mining in these regions. This substantial dependence of the country's electricity generation processes on freshwater supply triggers the rethinking of contemporary measures that encourage the country to adopt and implement climate change resilient strategies to sustain both water and energy supply. Although literature concedes interdependencies between these systems of water, energy and climate change, less attention has been paid to empirically examine this from the water management perspective and its influences on the development of adaptation and mitigation strategies such as policy. **Given this observation, this study seeks to investigate the extent to which the IWRM framework can be instrumental in ensuring that the WECC is analysed and understood in South Africa, therefore, capturing its risks and opportunities to promote sustainable development in the country.**

1.3. Research Questions

Given the above considerations, the research process was guided by the following questions:

i. What are the critical developments concerning the understanding of WECC across the globe and in South Africa?
ii. In what ways do the elements of water, energy and climate change demonstrate interdependencies in South Africa?
iii. Is the WECC nexus and its implications on SDGs understood in South Africa?
iv. How can the IWRM framework be implemented in enhancing the understanding of risks and opportunities associated with WECC nexus in South Africa?

v. What are the implications of the findings of the study on the holistic management of interactions between water, energy, and climate change in South Africa and regional contexts?

1.4. Research aim and objectives

In light of growing debates on the influence of WECC on SDGs, it is significant to understand how water, energy and climate change are linked to each other to develop effective tools to mitigate this nexus impact. Therefore the study utilises the IWRM approach to assess the occurrence of WECC nexus in South Africa. Given the aim identified above, the following objectives were set out:

i. Empirically examine the interdependencies between water, energy and climate change in South Africa mainly focusing on water-stressed catchments of Highveld and Waterberg regions;
ii. Use a Participatory Approach to assess how the interlinkage between water, energy and climate change is perceived by key stakeholders in South Africa;
iii. Analyse the effectiveness of IWRM in establishing approaches that will endorse a holistic and coordinated approach in WECC management;
iv. Contribute to the body of knowledge towards understanding the WECC nexus in South Africa.

1.5. Significance of the study

In light of the above discussions, the study is significant in the area of SDGs associated with water, energy and climate change. These significances are highlighted in three ways:

Firstly, this study seeks to promote an understanding of the magnitude of the interconnection and interdependency of the water, energy, and climate changes in South Africa. This will further help in providing mitigation measures and adaptation strategies to the risks that this nexus may be presenting to the country. *Secondly*, taking into consideration the sustainable development role that depleted freshwater play in the country, the study is significant in promoting insights that may lead to the effective management of water resources. Without proper management of this resource; challenges such as health issues, drought, economic collapse, as well as the loss of life may occur at an accelerated rate. Similarly, managing WECC

from the water resource management perspective could result in ensuring energy security, despite climate change influences. *Thirdly,* this study suggests some of the tools that can be used in assessing and addressing WECC related challenges. This should further accelerate the development of integrated systems which will incorporate water and energy planning while taking into consideration the climate change projections. The development of such strategies will promote understanding of the role that each element of nexus plays in each other sector thus encouraging effective planning and management.

1.6. Brief contextualization of literature

The section provides a brief literature contextualisation on WECC and IWRM implementation. However, a detailed account of different views and studies on WECC development and IWRM has been presented in Chapter Two of this thesis. The nexus studies have, in recent years gained attention from international literature due to the significant role that it has on sustainable development. The majority of these studies have, however, mainly focused on the inextricable linkage between water, energy, and food, thus resulting in the nexus configurations such as WE and Water-Energy-Food (WEF) (Prasad et al., 2012; Gulati et al., 2012; Cater and Gulati, 2014; Cullis et al., 2019). There is now an emerging discourse on the work done on climate change, water, and energy. This has been born out of the inextricable linkage of climate change to both water and energy resources. For example, it is argued that the rise in erratic climate conditions that severely impact on the production of key resources such as food and energy suggest that climate change be incorporated in WEF or WE studies (World Economic Forum, 2011; Jagerskog et al., 2014). Despite this observation, Liu (2016) pointed out that studies that integrate climate change factors within the production of these resources are at an infant stage and limited in poor and middle-income regions particularly those in the SSA. This necessitates the need to increase the focus on research that analyses the nexus configurations given evolving climatic conditions, particularly taking into consideration how these nexus affect societies in the SSA region.

Climate change has significant effects on water resources due to its predominant linkages with the hydrological cycle. For instance, Adams and Peck (2008), Natural Resource Defence Council (NDRC, 2010), DeNicola et al. *(*2015), Scottish Environmental Protection Agency (SEPA, 2017) and Nkhonjera (2017) concurred that climate change influence on water

resources is experienced through the occurrence of activities such as intensified precipitation, increased evaporation rates, high water temperatures, changes in the distributions and frequency of rainfall. These repercussions result in water shortages towards other subsectors of the economy thus fortifying the need to elude from excluding climate change in societal and economic related studies. One of the key studies that focused on climate change influence on water and energy concluded that, despite being understudied as compared to WE and WEF, WECC occurrence is one of the main emerging challenges affecting societal needs negatively (Cammerman, 2009; Head and Cammerman, 2010).

It is further argued by Cammerman (2009) and Head and Cammerman (2010) that WECC nexus can be assessed from the water resource management perspective. This is prompted by the centric role that, despite being heavily influenced by varying climatic conditions, water plays in the energy generation sector. In the SSA, which heavily depends on water-driven technologies such as hydropower and coal-combustion, Urama and Ozor (2010) are of the view that the region's water shortages are critically affected by a multitude of instant and long-term impacts of climate change. Studies in several regional countries such as Kenya, Democratic Republic of Congo and Cameroon revealed that their electricity generation is frequently reduced due to water shortages driven by climate repercussions such as drought and floods (Mukheibir, 2008; Prasad et al., 2012; Conway et al, 2015). These persuaded different actors to suggest studies that will incorporate climate change impacts when assessing the nexus and its impact on regional developments.

In South Africa, this study reveals that the occurrence of different nexus configurations such as WECC and WEF is unavoidable. In the context of WECC, for instance, despite being one of the water-scarce countries around the world due to factors such as its semi aridity, it is argued that the country is regarded as a climate change hotspot and one of the top emitters of GHGs across the globe (IPCC, 2007; WRC, 2009; DWS, 2013; Nkhonjera, 2017). These GHGs are largely due to water-reliant energy systems, particularly coal combustion which produces approximately 90% of the country's energy (Eskom, 2012). This is despite the country's water shortages which are attested by the existing over-allocation (as illustrated in Figure 1.1). These water shortages are aggravated by factors such as increasing temperatures, variable rainfall events, drought, and floods (DWS, 2013). Studies by Water Research Group (2009), Hughes et al. (2012) and the Department of Energy (DoE, 2013) have suggested that the projected increase in demand for water and energy in the country intensifies the need to improve the

security of these resources, particularly considering the overarching role that climate change plays in their supply. Despite these observations, there is limited research that links climate change with water and energy resources in the country. This study, therefore, is crucial in contemporarily assessing this nexus to ensure its risks and opportunities towards the country's national developmental objectives are captured.

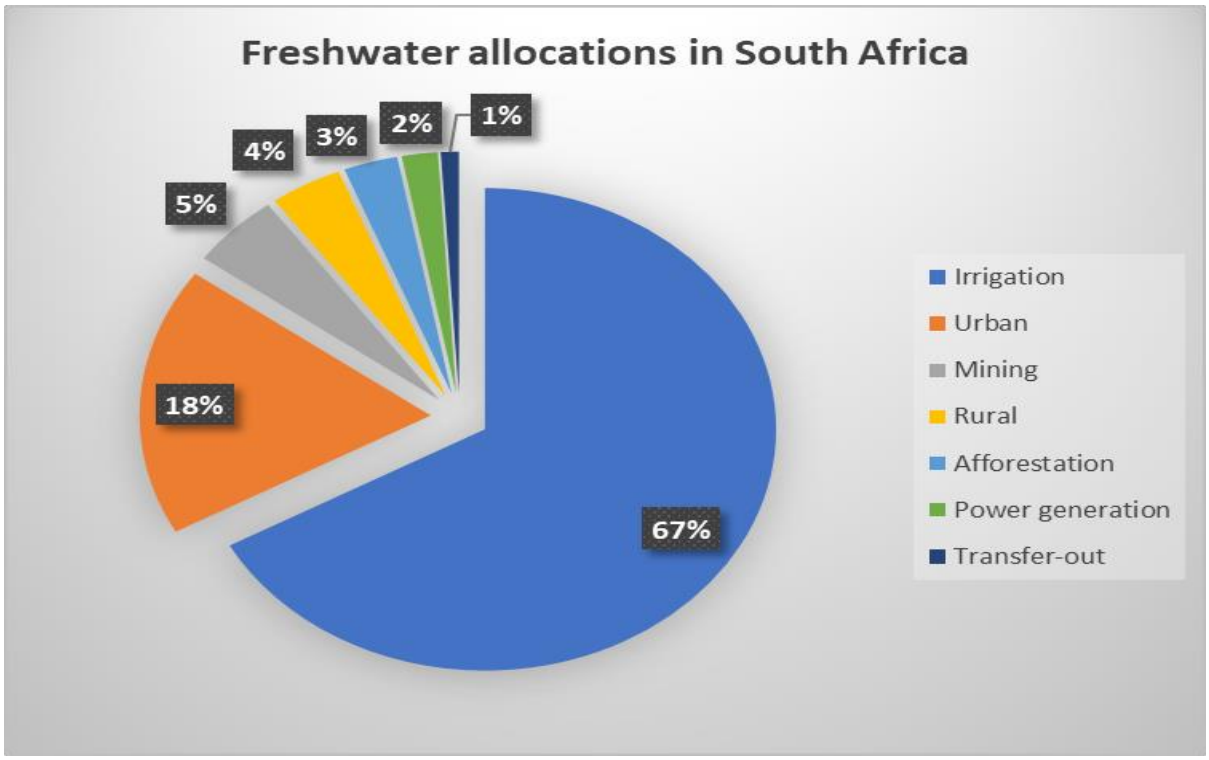


Figure 1.1: Water allocations for various socio-economic sectors in South Africa
Source: DWS (2013)

The lack of integrated and holistic approaches in the management of WECC is widely reported as a concern for most communities such as South Africa (Mabhaudhi et al., 2018; Nhamo et al., 2018). This persuades researchers to investigate and develop contemporary measures to manage different nexus configurations. One particular tool argued to be effective in coordination and integration of complex systems such as WECC is the IWRM framework (Cammerman, 2009; Head and Cammerman, 2010). This framework is defined by various actors as a risk-based approach that promotes and coordinates the management of water and land-related activities thus ensuring effective management of water resources (GWP, 2000; Cammerman, 2009; Bindra et al., 2013). In South Africa, Pollard and du Toit (2008) are of the view that this framework is viable as either a philosophy, process or management strategy that is applied to ensure sustainable use of water by all users at catchment, regional, national and international levels while maintaining the characteristics and integrity of this resource at the

catchment scale within agreed limits. According to GWP (2000), the IWRM is based on "4 principles that recognize the following:

i. Freshwater as a finite and vulnerable resource, essential to sustain life, development, and the environment;
ii. Participatory approach in water management and development;
iii. Recognition and inclusion of women as they play a central part in the provision, management, and safeguarding of water resources; and
iv. The economic value of water resources among all its users."

The GWP (2000) further illustrated how the integration of IWRM into sustainable water resource management objectives as well as implementation strategies must be adhered to yield the desired results. As illustrated in Figure 1.2, the establishment of management instruments and institutional frameworks are suggested as some of the effective implementation strategies aligned with the IWRM. Despite the framework being promoted by different global communities, studies by Rahaman et al. (2004), Biswas (2004, 2008) and Heldt et al. (2017) have pointed out that lack of a well-defined clear implementation strategy is one of the shortfalls of this framework. Nevertheless, case studies implemented in South Africa are content that this framework is effective towards promoting the country's sustainable water resource management (Funke et al., 2007; Pollard and Du Toit, 2008). As such, this study further investigates the possibility of adopting this framework in the management of WECC, an approach that is untested across the globe.

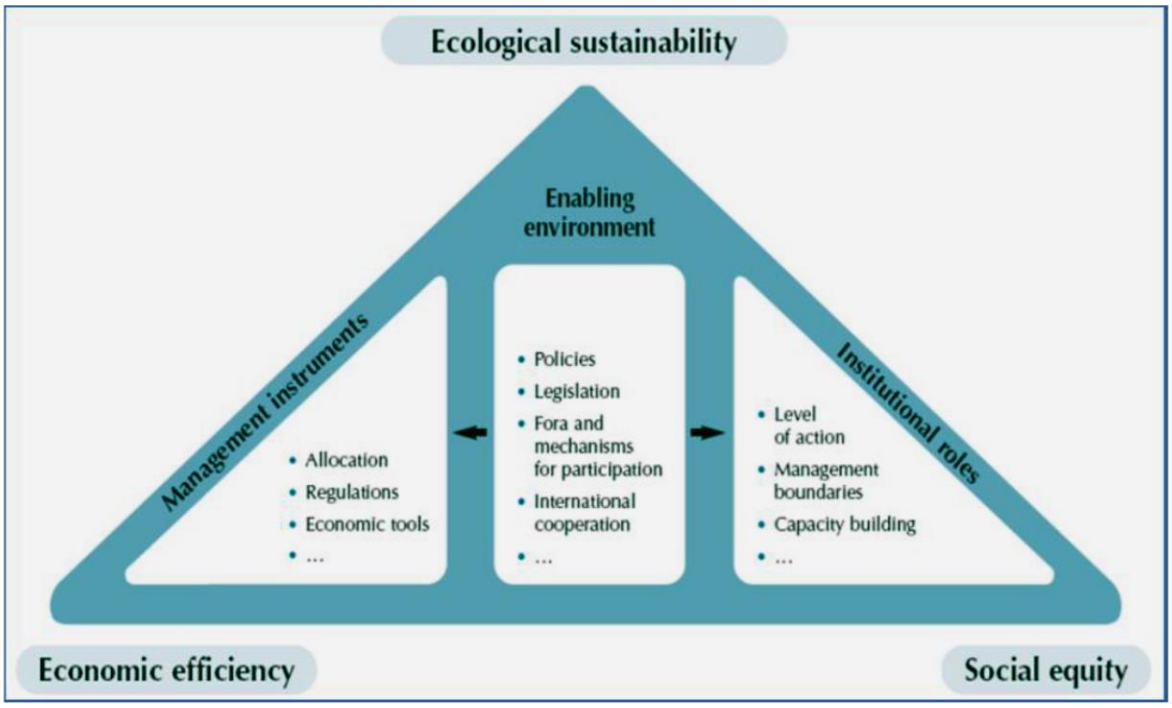


Figure 1.2: The general framework for IWRM
Source: GWP (2000)

1.7. Research Design

This section gives a brief description of the overall methodological framework that was adopted in this study. It briefly outlines the philosophy, description of the approaches followed, characteristics of the case study areas and ethical considerations. The detailed methodological approaches are mainly described in each chapter (Chapters two, three and four) of this thesis.

1.7.1. Research philosophy

Guided by the nature of the research, this section elaborates on the approaches used in undertaking this study. Carr (2006) explained that the research approach highlights the application of the principles to justify the types of methods and philosophies as far as a particular study is concerned. Social researchers stipulated that a study can follow two main types of approaches being qualitative and quantitative. For instance, Denscombe (2008) explained that a quantitative approach in research is mainly associated with positivism. In this approach, the study's approaches are based on measurements and counting (Saunders et al., 2009; Bryman, 2012). Bryman (2012) further contends that this research approach mostly uses physical data to achieve research objectives and the results are mainly presented in the form of tables and graphs. Contrary to positivism, Bryman (2012) pointed out that the naturalism

approach uses tools such as observations and questions to attain their research objectives. In studies of this nature, Bryman (2012) and Charmaz (2013) concurred that reality changes and the views of participants are motivated by the people's interpretation and attitude. Therefore, this approach focuses more on human behaviours hence it is termed qualitative analysis (Charmaz, 2013, Van Zyl, 2014). Based on these observations, either of these approaches can be chosen to dictate the selection of tools to be used in collecting data in a particular study.

1.7.2. Methodological approach

The nature and complexity of this study permitted the application of a mixed-methods approach, which involves the use of both qualitative and quantitative approaches to address research objectives (Bless et al., 2013). The application of both these approaches, as illustrated in Table 1.1, allows for the attainment of the research objectives through a credible and validated manner. In the first instance, a rapid appraisal of the literature on the study subject was conducted. In total, approximately 250 documents such as published papers, reports, and policy documents were reviewed to provide an overview of the development of the subject matter. Also, the study combined both primary and secondary data to attain empirical evidence that allowed for the research objectives to be achieved.

In a qualitative approach, the primary data were collected through gathering the perceptions of different stakeholders that play a pivotal role in the sectors of water, energy and climate change. The stakeholders included representatives from the government sector, water and energy utilities, research and academia, non-governmental organizations, donor-funders as well as independent experts. Research techniques tools that were used were one-on-one interviews, focus group discussions and the recording of participant observations. A semi-structured questionnaire was used to direct this data collection method. The perceptions of these research participants were analysed using a grounded theory approach.

In the quantitative approach, the secondary data, which mainly comprises of rainfall, GHG emissions, water, and energy statistics were attained from energy, water, and climate utilities (i.e. Eskom, South African Weather Services, Department of Water and Sanitation, Department of Environmental Affairs and Rand Water). Furthermore, the collected data were centralised around two study areas used as a case study which allowed for the delineations and in-depth inquiry of the subject by providing various sources of evidence and more variables rather than data points only. Applying a case study on data used to verify WECC interactions allowed the

research to focus on dealing with limitations and details of a complex situation (Denscombe, 2003). This case study was essential as it provided a comparative analysis of the results based on the geographical dissimilarities between the two areas while it allowed for the delineation of data collection points to the ground level.

Table 1.1: Summary of methods used to attain the study objectives

Objective	Research method
Empirically examine the interdependencies between water, energy and climate change in South Africa mainly focusing on water-stressed catchments of Highveld and Waterberg regions.	• Literature appraisal • Engagement with organizations such as Eskom and SAWS • Case study
Examine how stakeholders' perspectives can be gathered and used in assessing water, energy and climate change-related challenges in South Africa.	• Literature appraisal • Participants observation • Case study • Focus group discussion • One-on-one interviews
Analyse the effectiveness of IWRM in establishing approaches that will endorse a holistic and coordinated approach in WECC management.	• Discussions and interviews with experts\stakeholders • Literature appraisal
Contribute to the body of knowledge towards understanding the WECC nexus in South Africa.	• Literature appraisal • Engagement with different organizations • Focus group discussion • One-on-one interviews • Participants observation

1.7.3. Study Area

This sub-section provides a brief description of the geographical location and characteristics of the study areas. Although another sampling was done at a national scale, a justification as to why some vital information or data was delimited to these selected study areas is provided. The

regions of Waterberg (Lephalale Local Municipality) and Highveld (Emalahleni and Steve Tshwete Local Municipalities), illustrated in Figures 1-3 and 1-4 respectively, were selected for this study as they are deemed vital in the promotion of sustainable socio-economic development needs of the country (Emalahleni Local Municipality, 2019; Steve Tshwete Local Municipality, 2019; Department of Environmental Affairs [DEA], 2014). The Highveld region is situated in the Nkangala District Municipality and consists of the Emalahleni Local Municipality (2 678km²) and Steve Tshwete Local Municipality (3 976km²) in the Mpumalanga Province (Emalahleni Local Municipality, 2019; Steve Tshwete Local Municipality, 2019). On the other hand, the Waterberg study region forms part of the Lephalale Local Municipality (14 000 km²), which falls under the Waterberg District Municipality in the Limpopo Province (Lephalale Local Municipality, 2019). The physical characteristics of these two regions draw both similarities and differences. For example, as their contribution to atmospheric pollutants such as GHG emissions is noticeable, both these regions are declared air quality hotspots thus categorised as the Highveld Priority Area and Bojanala-Waterberg Priority Area respectively (DEA, 2007; 2014). Furthermore, their major rivers, Mokolo (Waterberg) and Upper Oliphants (Highveld) present some of the water-stressed catchments in the country due to their limited freshwater resource availability. For example, Dabrowsky and De Klerk (2013) observed that the Upper Oliphant experiences high levels of pollutants mainly attributed to anthropogenic activities thus further exacerbating water shortages in this catchment.

The other key similarity is the abundance of coal resources in these regions. The Highveld region has over the decades been the centre of coal mining in South Africa. Furthermore, the expansion of coal mining activities is planned as the regions' coalfields boast more than 40% of the total coal reserve of South Africa. As a result of the abundance of the coal resources in these regions, the Highveld houses eight coal-fired power stations with a build capacity of approximately 24066MW while only two, with a build capacity of 8400MW, are operated in the Waterberg (Eskom, 2019). In addition to these activities, other land uses such as agriculture occurs and contributes towards the country's National Developmental Plans (NDP) and associated environmental stresses. These regions' climatic conditions such as varying rainfall, water availability and temperature further presented noticeable differences that provided an opportunity to select them for a study of this nature.

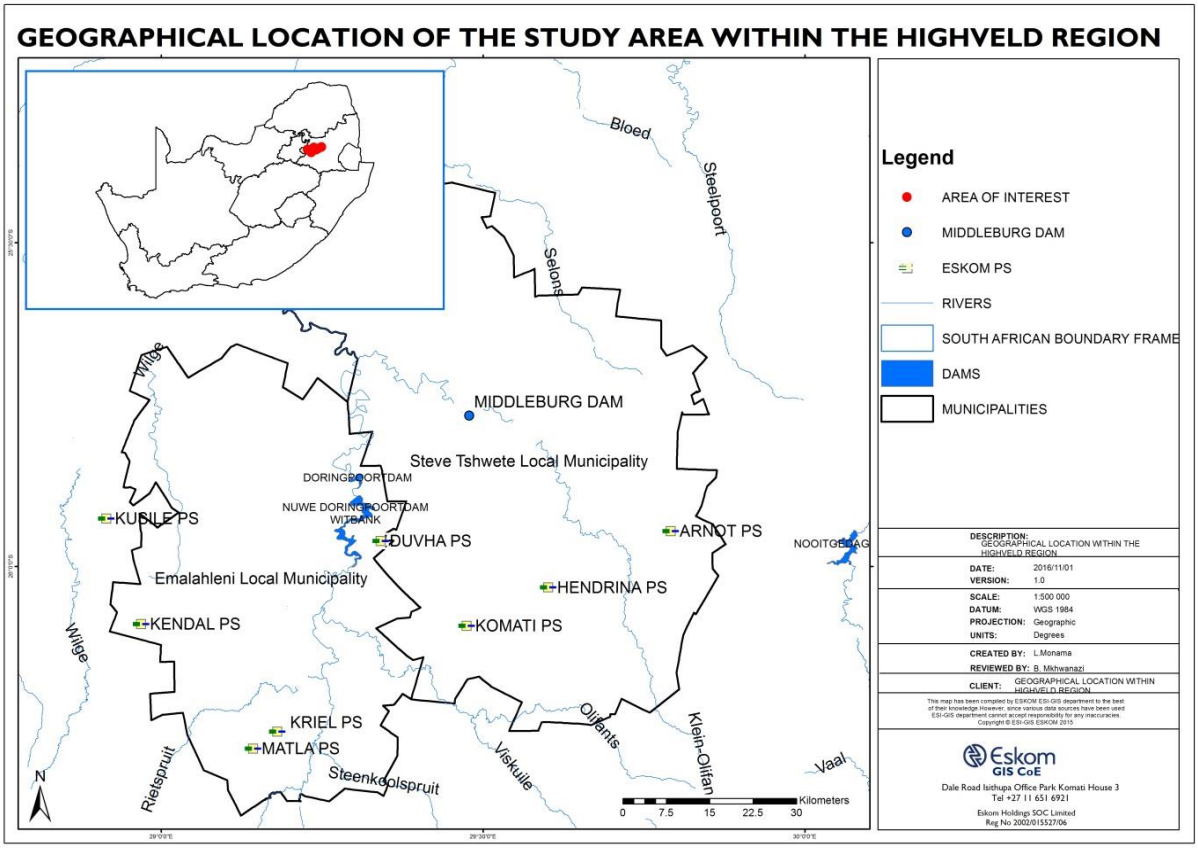


Figure 1.3: Geographical location of the Highveld region
Source: Eskom, Geographical Information Systems Centre of Excellence (2019)

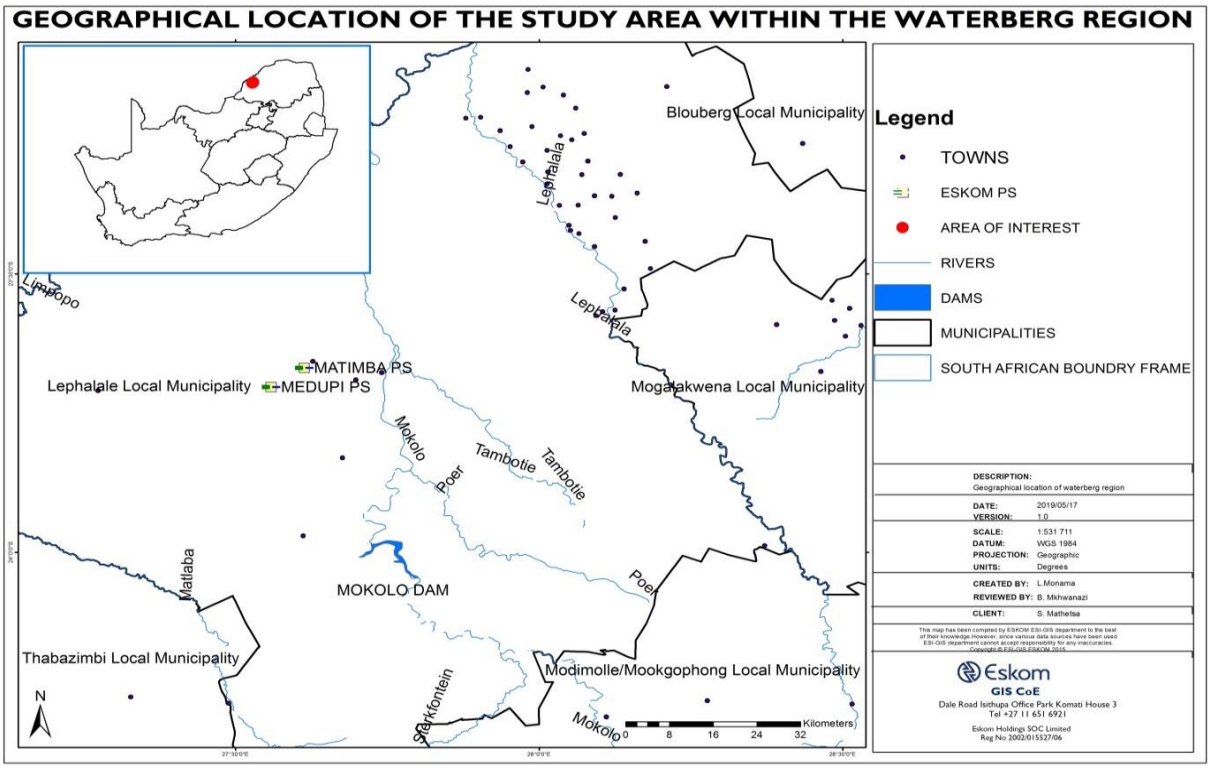


Figure 1.4: Geographical location of the Waterberg region
Source: Eskom, Geographical Information Systems Centre of Excellence (2019)

1.8. Scope of the study

This study's focus is on the linkages between water and energy systems under predicted climate changes in South Africa. Its application was limited to the two principles promoting water as a finite resource and participatory approach. This study had no intention to predict new climate change variations but relied on recent information to determine the influence that it has on water resources and energy systems. Lack of access to data at either study area or critical institutions limited assessment of the selected interactions of WECC components. The research participants who were engaged in this study may have had varying opinions regarding topics such as climate change and electricity generation methodology. However, this was not used to divert from the objectives of the study. Furthermore, the lack of willingness from other participants to take part in the study also comes in as a limiting factor to the data collection process.

1.8.1. Ethical considerations

The collection of data through the questionnaires, participants' observations, interviews with various stakeholders and gathering of the already collected data involved human participation and interactions. Yin (2014) emphasised that such a study should explain how human subjects will be protected. Bless et al. (2013) pointed out that the responsibility of ensuring that participants are protected against abuse or any form of risk lies with the researcher. Based on these, ethical clearance from the university was attained before the involvement of different participants. A clearance certificate (attached in Appendix A) was given following a commitment from the researcher to adhere to a considerable ethical approach towards this research.

1.9. Structure of the study

This PhD. thesis was carried out through the publication route. Thus, each chapter is based on a paper that has either been published, accepted for publication or under review in internationally recognized and accredited journals. Table 1.2 is a summary of each of the articles comprising this thesis.

Table 1.2: Summary of chapters

Chapter overview	Summary
Chapter 1: Introduction, background information, research question, aim and objectives, methodological considerations, research limitations, and ethical considerations	This chapter is a research conceptualization.
Chapter 2: Perspectives on IWRM and WECC globally, regionally and in South Africa. This chapter is based on a paper in the **Journal of Energy in Southern Africa**. Vol. 30, No. 3. 11-21. DOI: https://doi.org/10.17159/2413-3051/2019/v30i3a5654 (Published). FREE ACCESS: https://journals.assaf.org.za/index.php/jesa/article/view/5654	Assess the development around nexus studies, particularly WECC, across the globe and in South Africa. This chapter also briefly discusses IWRM and its relevance to understanding WECC.
Chapter 3: Assessment of the Water-Energy-Climate Change Nexus in South Africa: Towards the principle of water as a finite resource. This chapter is based on a paper titled: Assessing Water-Energy-Climate Change Nexus in South Africa: Towards water as a finite resource. **Development Southern Africa**. (Peer Review-Second draft)	Verify, presents and discusses the results on the occurrence of WECC in South Africa. This is done by quantitatively assessing several interactions of this nexus.
Chapter 4: Application of the participatory approach in assessing Water-Energy-Climate Change nexus in South Africa. This chapter is based on a paper titled: Application of participatory approach as an analytical framework for Water-Energy-Climate Change nexus in South Africa. **International Journal of Environment and Sustainable Development** (Peer Review-First draft).	Validate, presents and discusses the results on the perspectives of different key stakeholders on WECC occurrence in South Africa.
Chapter 5: Overall conclusions.	Synthesis, general conclusions, recommendations, and future pointers.

CHAPTER TWO

Perspectives on integrated water resource management and its relevance in understanding the water-energy-climate change nexus in South Africa[1]

ABSTRACT

It is increasingly acknowledged that the water-energy-climate change (WECC) nexus is one of the synergies that pose a significant risk to the achievement of sustainable development goals (SDGs), specifically numbers six, seven and thirteen. There are suggestions that climate change outcomes such as increased temperature and drought episodes have implications for water availability, which in turn affects energy production in countries dependent on hydropower, pump-storage or coal-generated electricity, including South Africa. This development, therefore, calls for improved understanding of how to effectively manage the challenges that arise from this nexus, to mitigate the impacts it may have on achieving the associated SDGs. This study, which is based on an in-depth appraisal of existing developments, assessed the potential of the integrated water resource management framework in understanding the WECC nexus and its implications for South Africa's sustainable development endeavours, particularly in the context of water resource management and utilisation. The study revealed South Africa's lack of integrated, effective, and efficient institutions and policy framework to comprehensively manage the challenges emanating from this nexus. It identified an urgent need to develop systems and processes through which South Africa can handle the challenges as well as capture the benefits that may be obtained from this nexus.

Keywords: climate change, energy security, water resource management, sustainable development

[1] This chapter is based on: Mathetsa, S.M., Simatele, M.D., Rampedi, I.T. and Gericke, G. 2019. Perspectives on integrated water resource management and its relevance in understanding the water-energy-climate change nexus in South Africa. **Journal of Energy in Southern Africa**. Vol. 30, No. 3. 11-21. **DOI**: https://doi.org/10.17159/2413-3051/2019/v30i3a5654 (Published). **FREE ACCESS**: https://journals.assaf.org.za/index.php/jesa/article/view/5654

2.1. Introduction

The sustainable development concept is premised on the assertions revolving around the objective to meet the needs of the present generation without compromising those of the future (Omer, 2008; Masters, 2009; Mathetsa, 2016). This definition embeds within itself the importance of identifying strategies and systems aimed at supplying and conserving resources within the socio-economic developmental needs of communities (United Nations [UN], 1972; 1992; Kubiszewski and Cleveland, 2012). This focus is regarded as a way of establishing a balanced system on how to effectively achieve economic and social progress within the limits of environmental sustainability, as well as aligning national development to the targets embedded in the sustainable development goals (SDGs). Increased global and local demands for resources in both domestic and industrial use have, however, exerted immense pressure on natural resources to a point of untenable management. Chilundo et al. (2008) and Brazilian et al. (2011) have pointed out factors, such as a rapid increase in population growth, industrialisation and urbanisation, which are driving natural resources towards devastation. These remarks, therefore, instigate a re-examination of how resources are used and safeguarded in such a manner that SDGs are achieved.

As the supply of water and energy resources emerges as one of the central themes of modern human life, their global demand is expected to increase as the need to attain SDGs intensifies. The Global Water Partnership (2000) and Al Saidi (2017) have pointed out that water scarcity in most global communities requires that their security be treated as a main topical issue within sustainable development at large. It is, however, observed that obstacles such as rising climate vulnerabilities exacerbate water scarcity (Natural Resource Defence Council, 2010; Ziervogel et al., 2014; DeNicola et al., 2015; Nhamo et al., 2018), thus raising profound concerns as to how a sustainable supply of critical resources can be attained. This underlines the persistent necessity for society globally to strive for a balanced system across the management of natural resources.

Given the threat that shortages of resources are posing to SDGs, it is widely reported that food and energy production are amongst the essential socioeconomic sectors most vulnerable to these constraints (Carter and Gulati, 2014; Carpenter, 2015; Rasul and Sharma, 2016; Mabhaudhi et al., 2016). The extent of this vulnerability is likely to be experienced mainly in countries such as South Africa, where water availability and supply drives both electricity

generation and food production, while energy is one of the most critical drivers of water treatment and distribution (Carpenter, 2015; International Energy Agency, 2016; Nhamo et al., 2018). This points to the interconnection and interdependency between water and energy systems, which most developing countries are struggling with and striving to supply on a reliable and sustainable basis.

In many sub-Sahara African (SSA) countries, the interlinkage between water and energy remains significant in the region, particularly in countries such as South Africa where coal-combustion is still the main driver for electricity production. Energy generation through coal-combustion, however, is one of the biggest contributors to human-induced climate change through the release of greenhouse gases (Intergovernmental Panel on Climate Change, 2007; Omer, 2008) which is widely perceived to be threatening human existence and exerting enormous pressure on limited water resources (Mukheibir, 2008; Dennis and Dennis, 2012; Nkhonjera, 2017). These considerations further highlight the coupling between the systems of water, energy and climate change – the water-energy-climate change (WECC) nexus. Its occurrence in South Africa corroborates the findings of Head and Cammerman (2010) who argued that most global communities, particularly those at developing stages, are likely to be faced with the WECC nexus. These dynamics call for critical questions relating to the WECC management and its socio-economic and ecological interactions, in countries such as South Africa which have been identified as climate change hotspots (Ziervogel et al., 2014; DeNicola et al., 2015; Nhamo et al., 2018).

Despite the complex linkage of systems of water, energy and climate change, several studies have concurred that challenges such as the pragmatic lack of coordinated planning, policy integration, and a systematic approach impedes effective management of WECC and its components (Cammerman, 2009; Hussey and Pittock, 2012; Rasul and Sharma, 2016; Mabhaudhi et al., 2016; Stein et al., 2018; Nhamo et al., 2018). This challenge deepens doubts about the attainment of SDGs linked to these components. In developing countries such as South Africa, the risks associated with WECC are likely to be felt, as the lack of adequate and integrated management of water, energy, and climate change systems is intense (Scott et al., 2011). This necessitates the need to establish contemporary approaches that will broaden understanding of this nexus and effectively manage it in a way that positively contributes to sustainable development.

Within the WECC nexus, water is regarded as the central component (Walmsley et al., 2001; Prasad et al., 2012; Jagerskog et al., 2014). Its dominant role across various societal needs suggests that it is sustainable management would benefit energy security while adapting to climate change. This observation supports the need for a shift in paradigms and adopting approaches that would facilitate sustainable systems of water resource management to minimise socio-economic and environmental risks associated with the WECC nexus. Studies within the sustainability sector have proposed different approaches for protecting and utilising water, including integrated water resource management (IWRM). The GWP (2000) and Leendertse et al. (2008), for example, found that this framework's ability to raise sufficient awareness, while promoting practical guidelines in a systematic and integrated approach, makes it one of the most useful tools available to promote sustainable water resource management. Considering the dire state of water resources in South Africa, there is a need to explore the potential and value of implementing the IWRM framework to address the WECC conundrum.

The present study examined developments in the WECC nexus to explore its effective management through an integrative and holistic approach. Conducting a review on an emerging and complex subject such as WECC is a crucial contribution to providing dependable and general information regarding this nexus while identifying gaps that should be addressed. Bless et al. (2013) suggested that a review of this nature involves searching and studying of previous and current developments on the investigated problems without raising any controversy. The present study also explored the IWRM framework with the view to utilising it as a tool to widen the understanding and promotion of effective management of the WECC nexus in South Africa.

2.2. Methodology

This study examined the international developments, with an emphasis on SSA, especially South Africa, in water, energy and climate change systems, and thus the WECC nexus and IWRM framework. To this extent, a rapid appraisal of empirical academic and non-academic literature such as project and industry reports, books and presented papers was conducted. Additional developments were obtained from the Water Research Commission, a South African-based research institute that conducts and publishes studies within the water and environmental fields in the Southern Africa region. With a focus on themes such as sustainable water resource management, energy security, and climate change impacts, the criteria for

inclusion in the appraisal were based on global, regional and local studies focusing mostly on different nexus types such as WECC, water-energy (WE) and water-energy-food (WEF). This methodology was influenced by suggestions of the limited work done on WECC in South Africa, which is intensified by a lack of broadened knowledge, and a fragmented policy approach on the nexus. This appraisal was corroborated by extensive verbal interaction with a specialist within the field of WECC to gain further information on this nexus and its challenges within the SSA region.

2.3. Results and Discussion

2.3.1. Contextual developments on WECC nexus

The SDGs numbers six, seven and thirteen underline the need for global communities to maximise the reliable supply of water and energy, while combating climate change and its related impacts (UN, 2015). Communities in SSA are faced with similar expectations. In South Africa for example, Winkler (2006) expressed the view that most of the country's socio-economic developmental needs could be achieved through an increased supply of energy. This, however, must be done within the parameters of safeguarding natural resources such as water, land, and atmosphere. Although the need to address societal and ecological imperatives is intensifying, studies have mentioned the complex interlinkage between some of the key features of modern life as one of the synergies halting their attainment (Head and Cammerman, 2010; Bazilian et al., 2011; Pahl-Wostl et al., 2018). Among those interlinkages, the complex connection between the systems of water, energy, food and, more recently, with the consideration of climate change, gives rise to different forms of nexus. With uncertainties emerging from these nexus, concerns over the reliable supply of resources such as food, water, and energy, as well as their contribution towards climate change intensify. On the other hand, climate change impacts the availability of these resources in numerous forms.

Recent studies have made contrasting reports about when and how the nexus within the sustainable management discourse emerged (Siddiqi and Anadon, 2011; Conway et al., 2011; Muller, 2015; Pahl-Wostl et al., 2018; Simpson and Jewitt, 2019). While initial studies around the nexus are mostly limited to water and energy interactions and in some instances incorporate food production, Siddiqi and Anadon (2011) suggested that the need to acknowledge and understand the WE nexus was recognised as early as 1994. Muller (2015), however, asserted that recognition of such interlinkages arose as early as the 1970s. Irrespective of when it

emerged, the socio-economic influence of the nexus encouraged its discussions at various global gatherings during the 2000s. For example, conferences such as the Gleneagles G8 Environmental Ministers' meeting in 2007, the Davos World Economic Forum in 2008, and Bali's United Nations Framework Convention on Climate Change meeting in 2008 resolved to strengthen the understanding and management of the water and energy interactions (European Cooperation in Science and Technology [COST], 2009; Cammerman, 2009). Furthermore, the Bonn Nexus conference in 2011 reflected mainly on the interactions of water and energy together with food production, resulting in more studies embracing the triangular WEF nexus (Conway et al., 2011). These observations fortified the discussions and investigations around various types of nexus to gain momentum in both policy and research perspectives.

Until recently, most studies did not consider the impact of climate change on the nexus configurations. Climate vulnerability studies prompted global researchers to consider their role in food, energy, and water security. Studies in countries such as the United States (US), China, Spain, and Australia were the first to focus mainly on the WE with brief considerations of climate change influence. For example, Hussey and Pittock (2012) found that the WE study conducted in the US in 2006 was one of the initial researches that embraced the climate change role in the nexus. This and other subsequent developments resolved to fully incorporate climate change in coupled triangular interactions of water and energy.

Despite the emerging interest in the WECC nexus and its sustainable developmental impacts, studies on the in-depth understanding of this nexus and its consequences are still limited. This is confirmed by limited documented information on this nexus both at a global and regional level. Platonova and Leone (2012) and Yillia (2019) pointed out this as a concern for developing countries, particularly those in the SSA. Nkhonjera (2017) suggested that this region's lacking behind on understanding climate change and its influential role in other sectors such as water and energy is attributed to uncertainties in climate and hydrological modelling, lack of financial resources and political will to develop and implement policy, particularly in developing regions. This raises resistance in recognition of paradigms such as WECC as well as policy development within them and is confirmed by recent studies in the SSA countries of Cameroon, Kenya and South Africa where WE and WEF nexus are still at the centre stage (Platonova and Leone, 2012; Ackom, 2014; Carter and Gulati, 2014; Mabhaudhi et al., 2016; Wakeford, 2017; Yillia, 2019).

The interlinkage between water, energy and climate change is a complex one, accentuated by interdependencies in multi-sectoral systems. For example, studies by Carpenter (2015) and Copeland and Carter (2017) observed that a substantial part of the global energy production systems heavily depends on water availability for various processes such as raw material extraction and cooling. Conversely, the treatment, supply, and usage of water, particularly in domestic and industrial practices, is an energy-dependent process. This interdependency is intensified by the distance of water users from water resources, which exacerbates energy needs in the water value chain. Conversely, the global over-reliance on energy production on the fossil fuel combustion processes results in the emission of greenhouse gases, which accelerates climate change. Despite climate change's influence on energy generation processes such as cooling, Ziervogel et al. (2014) and Kundzewics et al. (2016) concurred that its role in water availability is pivotal, as occurrences such as varying temperature, floods, precipitation, and drought affect the hydrological cycle. These varying climatic conditions and other impacts such as water pollution exacerbate water shortages, thus putting pressure on energy production and its associated sectors. The severity of this water, energy and climate change interdependency is experienced on a global scale already. For example, studies by Siddiqi and Anadon (2011) and Carpenter (2015) pointed out that some countries in Europe, South America, and Asia had to reduce their electricity production because of water shortages intensified by climate variabilities, particularly drought and increased temperatures.

The SSA, a rapidly developing region characterised by prolonged water shortages because of its semi-arid geographical characteristics and increasing energy demands, is not immune to WECC and its challenges. For example, while the region is striving to meet modern energy and water demands, Serdeczny et al. (2015) observed that this region is one of those where climate change outcomes will most be felt, in several sectors. Furthermore, Prasad et al. (2012) and Conway et al. (2015) indicated that drought and freshwater shortages in hydropower-dependent countries such as the Democratic Republic of Congo, Lesotho, Malawi, Kenya, Zimbabwe, and Zambia resulted in disruptions to the supply of energy. Despite these noticeable impacts of the WECC on the region's socio-economic developmental needs, it is observed that WE and WEF are still at the centre stage of nexus researches. Ackom (2014), Stein et al. (2018) and Yillia (2019), however, suggested that the region should intensify how it considers climate change's role on WE and WEF, thus presenting the SSA with opportunities to look at prospects of managing WECC effectively.

South Africa is one of those SSA countries likely to be affected by risks emanating from WECC. For example, despite the country's well-documented water scarcity status, approximately 90% of the electricity is generated from water-reliant coal-combustion, nuclear, hydropower and pump-storage technologies (Eskom, 2016). Being one of the epicentres of the national developmental plans, power generation is supplied with 2% of the freshwater available in the country with reliable assurance, second only to the agricultural sector (Eskom, 2012; Department of Water and Sanitation [DWS], 2014). The country is, however, ranked among the top producers of greenhouse gases, largely because of emissions from the power generation sector, specifically the coal-combustion technology (Carter and Gulati, 2014). The upsurge of climate change and influence from other anthropogenic activities such as urbanisation, exert pressure on already constrained water and energy resources. These observations show how the systems of water, energy and climate change are inextricably interconnected in the country, as elaborated in Figure 1. However, just like a situation in the global and regional context, the country has demonstrated a lack of knowledge and integration concerning managing the WECC and its risks. However, recent studies such as those by Mabhaudhi et al. (2016) and Nhamo et al. (2018) concurred on the need to effectively manage the nexus in a holistic and integrated manner. The present study, therefore, suggests the need for the country to broaden its understanding of the WECC and to initiate discussions such as policy integration to combat the risks associated with this nexus.

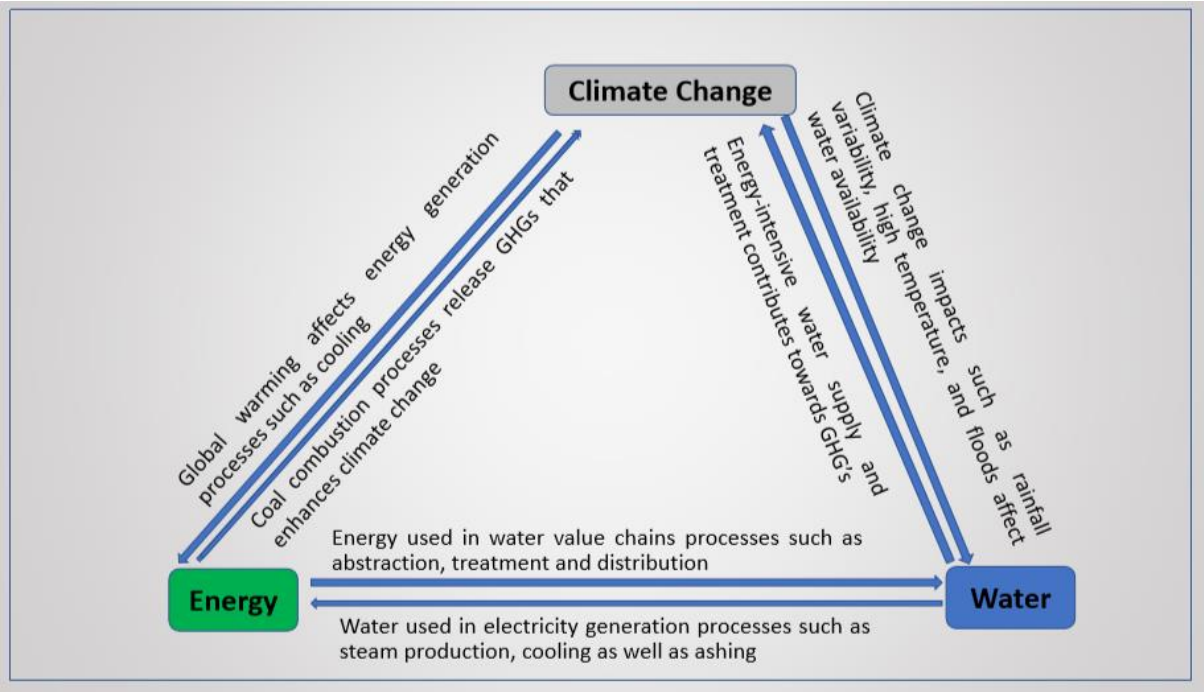


Figure 2.1: Coupled interactions between water, energy and climate change in South Africa.

2.3.2. Governance of the WECC nexus

Earlier investigations on WECC highlighted that partial understanding of this nexus results in a 'silo' approach, especially from the governance perspective (Cammerman, 2009; Head and Cammerman, 2010). Lack of a coordinated planning system, practices and policy development between the sectors of water, energy and climate change is a concern in many countries. Investigations are, however, gaining momentum elsewhere to minimise these governance setbacks (Goldstein et al., 2008; Energy and Water Integrated Act [EWIA], 2009). For example, the US study on WE recommended the development of an integrated policy on water and energy (Goldstein et al., 2008). In response, the EWIA policy was developed with the view to direct the US towards improving governance of the nexus through an in-depth analysis of the impact of energy development and production on the country's water resources (EWIA, 2009). Despite not being signed into law, this strategy encouraged other parts of the US and other countries to broaden investigations of various nexus studies in an integrated manner. For example, subsequent investigations and publications of reports such as the 'Water-energy nexus: Challenges and opportunities' (United State Department of Energy [US DoE], 2014) show efforts to promote a systematic, integrated and proactive way to address the nexus to ensure a reliable supply of energy under different water and climate constraints.

Despite such efforts and progress on incorporating all nexus components in planning, some countries still lag. South Africa is one of those that still approach governance of water, energy and climate change policy and implementation in isolation. Studies by Mabhaudhi et al. (2016) and Nhamo et al. (2018) showed that sectoral approaches driven by sector mandates which seldom refer to each other are cause for concern about effective governance of these systems. This is despite the country's adoption of the National Environmental Management Act, Number 107 of 1998, which endorses the integrated environmental management approach as one of its objectives. This policy segmentation demonstrates a fragmented approach and a lack of collective effort from the key stakeholders in the management of energy, water, and climate change. For example, with policies such as the National Water Resource Strategy (NWRS) in place, the Department of Water and Sanitation (DWS) is mandated to ensure that management and protection of water resources in South Africa are fulfilled (DWS, 2014). Water policies mostly acknowledge the impact of climate change on water resources, but without providing a plan as to how these will be dealt with. Policies relating to water resources' adaptative and resilient strategies on climate change are developed by the Department of Environmental Affairs (Department of Environmental Affairs [DEA], 2015). This is a concern, as there would be an overlap in terms of implementation. Furthermore, despite assurances on freshwater supply for the energy sector, water resource constraints highlight the need for integrated planning to secure water supply for power generation. However, recent delays in aligning water supply to energy generation raise gaps in terms of policy planning and implementation between these sectors. Similar misalignments are observed in energy planning. For example, despite proposing a mix that will decarbonise power generation sector with reduced water consumption, the 2010–2030 Integrated Resource Plan (IRP) highlights that 65% of the country's energy will still be generated using the water-reliant coal combustion process (DoE, 2010). This policy is silent on how the power generation sector will be reliably supplied with water and provides little suggestions on the improvement of water management at the operational level.

Furthermore, the IRP offers no strategy as to how the energy sector will reduce their greenhouse gas emissions from coal-fired power stations, except through decommissioning of power plants. Additionally, Madhlopa et al. (2016) noted that the IRP hardly addresses the water impacts resulting from the lifecycle of energy production, mainly raw material extraction such as coal mining, which is seen as the responsibility of the Department of Mineral Resources. The National Climate Change Response Policy was drafted to manage challenges emanating

from climate change (DEA, 2015). The policy further recommended that the adaptation strategies be implemented within the NWRS, while climate mitigation strategies in the energy sector include the reduction of carbon emissions (DEA, 2015). Trollip and Bouller (2017), however, contended that this policy can be attributed to a lack of coordination and alignment between the different role players in DEA, DWS, and DoE.

These observations point to a critical gap emerging from the governance of WECC components, where governmental structures still operate in a segregated manner in South Africa. This gap owes much to the unaligned institutional and policy framework within which a coordinated and integrated approach towards the management of water and energy resources in the context of climate change can be pursued. Several studies suggest delineating this complex issue to effectively address it. For example, in addressing myriad water issues, developing a consensus that proposes a shift towards 'nexus thinking' when addressing issues related to the WECC is an imperative one (Global Donor Platform for Rural Development, 2017; Taylor-Wood and Fuller, 2017). Reynolds and Cranston (2014) further suggested that nexus thinking can respond to the risks associated with different configurations. Nexus thinking is intended to promote viewing a specific problem from different angles to create an understanding of the bigger picture holistically and systematically while addressing other associated systems. Therefore, considering its centrality in WECC, an approach where water-related challenges are addressed while equally considering issues arising from energy and climate change could be an effective solution for this nexus. In Australia, studies by Cammerman (2009) and Head and Cammerman (2010) suggested that this integrated approach could be achieved through the implementation of the IWRM framework, which emerges from the water management perspective.

2.3.3. Towards the integrated approach

While the developments on nexus are still at an infant stage, research conducted on sustainable water resource management resulted in the paradigms such as the IWRM, which focusses on addressing complex systems involving water (GWP, 2000; Pollard and Du Toit, 2008; Heldt et al., 2017). This research stimulated suggestions that effective management of water should be at the apex of WECC as it may influence how to minimise the nexus risks to socio-economic development (Prasad et al., 2012; Jagerskog et al., 2014). Cammerman (2009), for example, asserted that lack of broadened understanding of the complexities and interactions around

WECC may result in unsustainable management and utilisation of water, which crosscuts most sectors, including food production. The question raised in this study is, however, how the efficient management of water resources presents an amplified system that builds their resilience towards climate change, thus easing energy insecurity and the associated sustainable development threats.

While different approaches towards managing water may be applicable, Cammerman (2009) and Bindra et al. (2013) contended that the IWRM approach is one of the useful tools that can endorse structure and mutually enforce management of this resource holistically and sustainably. Despite this framework being around for some time, Biswas (2008) and Nesheim et al. (2010) maintained that it only started being amplified by scientists and the GWP around the 1990s, and was strengthened only around the early 2000s. Initial discussions at various gatherings such the Dublin's UN-Water and Environment Conference in 1992, Rio's World Summit in 1992, Bonn's International Conference on Freshwater in 2001, and the Johannesburg World Summit on Sustainable Development in 2002, intensified the need to implement this framework for improved water resources management. Furthermore, the usefulness of this framework was recognised by at least 65% of countries which adopted it before the Rio Plus Conference in 2012 (Al-Saidi, 2017).

According to GWP (2000), this framework can shed light on how to develop regulations and regional plans for water governance in an integrated manner. This will ensure effective environmental management while defining institutional roles and stakeholder participation within the management of water resources. Studies within water resource management, however, show that this framework continues to receive criticism from some practitioners and scientists (Biswas, 2004; Fulazzaky, 2014; Heldt et al., 2017). For instance, Biswas (2004, 2008), found that the IWRM has demonstrated a lack of technical and institutional ability to address water resource challenges, thus resulting in setbacks regarding how it is implemented. This observation raises concerns within the water fraternity as to whether it is a practical tool to provide solutions for current and future challenges. Biswas (2008) further emphasised that this IWRM is not effective enough when applied across varying sectors such as agriculture and energy or even at a macro scale. Other studies, however, presented a different observation, arguing that IWRM can promote integrated management across different sectors such as energy, food production and water (Leendertse et al., 2008; Nesheim et al., 2010). Bringing together different water users with a common goal promotes integration as all views have the

potential to be considered in planning and policy development. Doubts about the effectiveness of IWRM resulted in other nations opting against its adoption. For example, some European countries opted to implement the European Union Water Framework Directive, a policy developed to provide alternative solutions to their water challenges (Heldt et al., 2017).

In many developing nations, such as those in SSA, lack of participation and political will still weaken IWRM's implementation. Muller (2015) raised factors such as the focus on growing the economy as well as climate vulnerability as some of the challenges impeding IWRM implementation in these nations. This underlines the need for a more robust and effective approach if water resource management improvements are to be attained. In South Africa, notably, challenges arising from coordination and policy implementation threaten the country's already stressed water resources to a point where its availability to sectors such as energy and food production cannot be guaranteed. Funke et al. (2007), however, maintained that, through a holistic and systematic manner presented in IWRM, this framework is a necessity if the country is to address its short-term risks and achieve long-term security of water resources, particularly those associated with scarcity and inequitable distribution, as well as mismatches identified in agriculture, industry and energy sector located on heavily concentrated water demand regions such as the Highveld in Mpumalanga. Funke et al. (2007) and Karar (2008), however, indicated that the country's application of IWRM is still limited to a water perspective or policy development within this sector.

Given that WECC components are governed in segregation despite the interlinkages, can this be mitigated by the IWRM's ability to influence governance through the promotion of a multi-participatory approach as well as consideration of different driving forces and their linkages? Cammerman (2009) suggested that this framework's proactive risk-based approach is one of its strengths, one that can promote an integrated approach on policies and strategies, while addressing associated challenges, particularly towards the socio-economic development agenda. This is despite it arising from the water resource management perspective.

2.4. Conclusions

This study examined developments in one of the emerging paradigms that threaten the achievement of sustainable development goals: water-energy-climate change (WECC) nexus.

The study revealed two key findings. Firstly, it is evident that studies of the WECC nexus are still limited internationally. Most nexus studies have, to date, focused mainly on water-energy and water-energy-food configurations. A similar observation is made in South Africa where there is an inextricable linkage between systems of water, energy and climate change. Secondly, despite gaps being identified in the management of different nexus configurations, South Africa still lacks policy integration. Currently, various government departments such as the Department of Water and Sanitation, Department of Environmental Affairs and Department of Energy generally address sectoral requirements instead of adopting an integrated approach. The study contributes towards closing the existing knowledge gap on WECC, thus assisting South Africa to understand and address myopia about the relationship between water, energy, and climate change, and promote discussions on an integrated approach in the development of institutional and policy framework.

CHAPTER 3

Assessing Water-Energy-Climate Change Nexus in South Africa: Towards water as a finite resource[2]

ABSTRACT

The constant supply of water and energy has become a cornerstone for sustaining modern socio-economic and national development. However, the interdependency between them, coupled with frequent changes in climate, threatens their continued supply and security. The interaction between these two life-sustaining resources and in the context of climate change is what is now commonly referred to as the Water-Energy-Climate Change (WECC) nexus. Anecdotal evidence associated with the projected risks of the WECC nexus has triggered research and policy interest across the globe, particularly in more advanced economies to have a comprehensive understanding of how to manage and minimize its impacts on socio-economic developmental goals. Despite this development, many less economically developed and middle-income countries such as South Africa are lacking behind in advancing systems and processes which will broaden their understanding of the WECC. This hinders progress in building their adaptive capacity and resilience against the impacts of this nexus. It is argued in this paper that for any country to broaden its understanding and build its adaptive capacity and resilience to the impacts of the WECC, appropriate quality and reliable data must be collected and exchanged with key stakeholders to facilitate and promote a well-coordinated response and develop systematic actions and strategic approaches to address the risks associated with the WECC nexus. Using rapid appraisal of existing information obtained from different organisations, this study quantitatively analysed both historical and contemporary data focusing mainly on the Waterberg and Highveld regions to understand the WECC interlinkages. The results of the study analysed and discussed within the discourse of the Integrated Water Resource Management framework particularly with the concession of water's status as a finite resource in South Africa, exemplify a series of interactions between the WECC components such as those of water for energy provision. This study further discusses the

[2] This chapter is based on: Mathetsa, S.M., Simatele, M.D., Rampedi I.T. and Gericke, G. 2019. Assessing Water-Energy-Climate Change Nexus in South Africa: Towards water as a finite resource. ***Development Southern Africa*****.** (Under Review).

importance of systems that will ensure acquisition, accessibility, reliability and quantifiable data to effectively influence decision-making processes and policy development.

Key Words: Water; Energy; Climate Change; nexus; Integrated Water Resource Management, South Africa, quantitative analysis

3.1. Introduction

The constant supply of water and energy resources has become an absolute imperative in sustaining modern life. The intensified need for the provision of these resources to enhance socio-economic development programs has resulted in an exponential increase in their demand at a global, regional, national or local level (Hussey and Pittock, 2012; Spark et al., 2014; Carpenter, 2015). Their supply, constrained by factors such as resource shortages, rapid population growth, and other anthropogenic activities is, however, complicated by climate change and associated environmental stresses. In recent years, the supply of these resources, together with the need to address climate change, has been one of the central points for discussions in the sustainable development discourse. These debates are intensified by the growing indications of how water, energy, and climate change elements relate to each other resulting in a phenomenon called Water-Energy-Climate Change (WECC) nexus (Cammerman, 2009). Anecdotal evidence shows that the existence of WECC has a negative influence on the attainment of environmental and socio-economic targets among communities across the globe consequently necessitating the need to manage the challenges arising from this nexus. These developments motivate the improvement of resilience and adaptive strategies that may alter the potential impacts emanating from this nexus.

Given the growing need for measures to ensure water and energy security while simultaneously combating climate change, the current actions seem to suggest a lack of understanding of how WECC components are interlinked. One way to demonstrate this dearth of integration is the existing segmented planning in policy development within the sectors of water, energy and climate change which is exacerbated by lack of integration and application of analytical tools to manage these WECC components (Bizikova et al., 2013; Rasul and Sharma, 2015; and Pahl-Wostl et al., 2018; Gobin et al., 2019). This policy segmentation, mostly observed in the developing and middle-income regions such as those in Sub-Saharan Africa (SSA), indicates a

lack of progress in implementing the principles of sustainable ecological and socio-economic development. The ”silo” approach on the policy planning and development within the WECC elements can largely be due to insufficient knowledge and lack of adequate information available to integrate these sectors. While there are calls for the implementation of coordinated and holistic planning on managing of WECC risks and opportunities (European Cooperation in Science and Technology [COST], 2009; Rahul and Sharma, 2016; and Cullis et al., 2018), development of such systems should be based on sound empirical evidence and broadened comprehension of the interfaces between water, energy, and climate change sectors.

Although WECC existences and its repercussions are, in general, experienced mostly in less-developed and middle-income countries such as those in the SSA region, it is particularly real for South Africa. For instance, the country’s scarce water resources play a central role in the current supply of energy, coal-combustion. This, in turn, contributes towards climate change which influences water availability. An observation by World Bank (2017) that constraints in water and energy supply in the country raises critical challenges towards the attainment of its national developmental plans, therefore, should persuade the country to strengthen its understanding and development of adaptive and resilient systems to effectively address the WECC nexus and its risks. Central to these challenges is, similar to most global communities, segmentation in the country’s policy planning within the sectors of water, energy, and climate change. Prasad et al. (2012), Mabhaudhi et al. (2016), and Nhamo et al. (2018), for example, observed that despite being highly reformed within themselves, the country continues to experience an intense “silo” approach in policy planning of the water, energy and climate change.

One way of validating the existence of interfaces between the WECC components is through a quantitative approach. This method allows for the presentation and analysis of different components over some time using physical data thus assisting in understanding the past and present trends (Bless et al., 2013). Also, Liu et al. (2017) and Aboelgna et al. (2018) concurred that utilisation of both physical and social data is critical in providing vital knowledge towards decision-making on issues related to different nexus configurations. The attainment of this view, however, depends on the availability, accessibility, and usability of physical data. The lack of systems to ensure reliable and quality data availability is demonstrated across the globe particularly in the less-economically and middle-income regions, thus hindering the provision of sufficient information for nexus and associated programs. In the SSA region, for example,

Yillia (2019) argued that broadened understanding and progress towards nexus integration are hindered by lack of information or data particularly at the grassroots level where most activities are undertaken. Similarly, in South Africa, limited data and information are seen to be some of the main reasons for current policy segregation and eminent nexus risks in the country (Gobin et al., 2019). This, in turn, limits the decision-makers to draft policy and systems to effectively manage the nexus. This observation primarily motivates for data analysis and subsequent understanding of the interactions between the water, energy and climate change to be used as a foundation for the development of resilient and adaptive systems to address WECC in a holistic and coordinated manner.

Different approaches are being looked into in analysing and understanding interactions of different nexus configurations with the view of managing it in an integrated manner. Bizikova et al. (2014) suggest that these approaches should be investigated using water as an entry point towards effective management of nexus configurations. Given this, Head and Cammerman (2010) argued that the WECC should adopt the Integrated Water Resource Management (IWRM) framework to promote a holistic, coordinated and informative approach towards this nexus. This approach is acknowledged to be able to holistically address complex systems that connect water and other 'related' resources such as energy and food (Global Water Partnership [GWP] 2000; Fatch, 2009; Fulazzaky, 2014). In South Africa, the suggestion to adopt the IWRM towards WECC is driven by the dire status of water resources in the country, which is predicted to worsen thus impacting socio-economic activities such as energy. This IWRM approach is, according to Bindra et al. (2014), able to consider other disciplines and involve all relevant stakeholders in formulating sustainable solutions to ensure equity and efficiency not only in water but other developmental challenges such as energy and food production. The information related to water could, therefore, explore its coupling with energy and climate change thus enabling holistic management of these elements.

Based on the above discussions, this study investigated the WECC interlinkages in South Africa through the analysis of physical data. Specifically, the objectives of this study were to provide rationale towards the significance of quantitative approach in substantiating WECC existence to (1) propose the integration of policies and strategies based on sound empirical evidence, (2) improve on data accounting, accessibility, reliability, and quality to solidify its importance in WECC and (3) broaden the knowledge of this nexus configuration in South Africa. A rapid appraisal of literature solidifies an argument of how water limitations

experienced in the country motivate IWRM's role towards WECC understanding and management particularly within the discourse of ‘water as a finite resource’ principle. This study uses secondary information obtained from different stakeholders to analyse and draw conclusions regarding the existence of WECC interchanges. Finally, recommendations of possible actions to remedies security threats associated with WECC are presented.

3.2. The significance of the IWRM Framework towards the WECC nexus

Although several scholars define the IWRM differently, its initial goal remains the promotion of sustainable water resource management. GWP (2000, pp 6), for example, define the IWRM as “a process which promotes the coordinated development and management of water, land and related resource, to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem”. This definition is embedded in the need for coordinated and effective management of all aspects of water such as the surface and groundwater and their hydrological boundaries as well as ‘related resources’ depending on or influencing this resource availability. In this case, dissimilarities that occur in aspects such as food and energy generation, domestic utilisation as well as climatic variables are highlighted as influencers or attributes from the interactions between human-induced processes and natural systems such as water (Funke et al., 2007; Bindra et al., 2014).

Similar to any policy, strategy, process or system, the IWRM’s effectiveness is determined by how it is implemented (Biswas, 2004; Heldt et al., 2017). GWP (2000), for example, base the effective implementation of this framework on its ability to develop an enabling environment, institutional roles, and management instruments that address water-related concerns. While it is argued that the IWRM should not be viewed as a replacement for policy, its principles should be able to facilitate the development of such strategies, tools or management guidelines which would trigger sustainable water resource management. As part of its water reform, South Africa has also been subjected to the implementation of the IWRM approach. To support this view, Pollard and Du Toit (2008) observed that this framework is used in South Africa to facilitate sustainable use of water by stakeholders at catchment, regional, and even beyond the countries with shared resource basins. Furthermore, the IWRM framework is believed to have enabled the country to develop administrative tools for enhancing sustainable water resource management. For example, the post-apartheid water reforms, which were centralised around the need for equity, efficiency and sustainability in the use and protection of water, resulted in the utilisation of IWRM approach in developing policies and strategies such as National Water

Act, 36 of 1998 and National Water Resource Strategy (DWS, 2004, 2013; Berjak, 2003; Karar, 2008; WRC, 2009; Pollard and du Toit, 2008). The application of this framework in some parts of South Africa has, however, not been effective particularly at ground level. Claassen (2013), for example, attributes this to factors such as limited experience, information, capacity and innovation among various stakeholders. This raises concerns as to how effective water resources and related aspects are managed at the grassroots level as this potentially impact on water security, which in turn, affects socio-economic, industrial and ecological activities.

Although the IWRM's main focus is on water resource management, Cammerman (2009) and Fulazzaky (2014) argue that this framework can be considered as a tool to manage complex systems, particularly those induced and generated by human interaction with nature. The WECC nexus provides a good example of those complex configurations as it elaborates on the inextricable linkage between the systems of water with energy and climate change, elements that are closely linked to human activities. Given its gravity, holistic and integrated management of WECC in a manner that influences the development of systems and processes becomes an absolute imperative. This study, therefore, engaged with the IWRM, both as an operational and analytical framework for addressing challenges associated with the WECC.

3.2.1. Water is a finite resource in the South African context

The IWRM framework is centralised around 4 principles. One of those principles emphasises the necessity to fully recognise the finite and indispensable nature of freshwater (GWP, 2000). Driven by the deteriorating water status across the globe, this principle compels communities to adopt a holistic and coordinated approach in the sustainable management of water resources (GWP, 2000; Funke et al., 2007; National Resource Defense Council, 2010; Carpenter, 2015). The notion of holism promotes the management of systems focusing on wholes rather than analysis or separation into parts. GWP (2000) and Funke et al. (2007), therefore, contended that this holism approach within water resource management can be undertaken through consideration of factors such as hydrological cycle and the role it plays towards other sectors, various arrangements or landscape of a particular region. It is, therefore, suggested that interaction between uses and users at various scales as well as governance practices form the basis for holistic management of water at a local, regional or global scale particularly considering its limited availability. This can, according to Cammerman (2009), be achieved through the integration of water resource management within developmental planning in a manner that eliminates segregation of processes such as policy and analytical tools.

The overreliance of water and energy systems on each other presents systematic challenges towards socio-economic developmental needs as it raises concerns over the security of supply of these resources (GWP, 2000; Hejazi et al., 2014; Cullis et al., 2018). Moreover, water resources security is under more scrutiny because of its intimate linkage to climate change and, unlike energy, is limited in terms of alternatives. Within the SSA region, South Africa provides an example of an illustrative water resource predicament in several ways. Firstly, its semi-aridity, lower rainfall characteristics, deteriorating water quality resulting from anthropogenic activities and over-allocation (DWS, 2014), suggest that its water resources are undoubtedly finite. Secondly, its vulnerability towards climate change, as asserted by Nkhonjera (2017), drive the current water status towards persistent deterioration. And lastly, its central role in the country's various socio-economic activities such as energy and food production persuades for the development of effective adaptation and mitigation measures to use and protect these limited water resources and this can be a costly exercise.

Despite these complications, the current water resource administrative tools in South Africa are believed to be insufficient to address possible risks and opportunities (DWS, 2014). This is likely to influence the multiple systems heavily linked with water thus affecting the attainment of the country's national developmental plans. Concerning this study, the largest "strategic water user" of water in the country, energy, as well as consequences resulting from climate change are identified as some of those sectors closely linked to water resources. Therefore, despite being water-centric, advocating for the finite status of water resources as a central theme of WECC can provide greater understanding and identification of risks associated with the nexus in the country. Funke et al. (2007), for example, emphasised that South Africa should adopt an inclusive dimension that would consider all hydrological cycles and water's interactions with other resources and the ecosystem.

3.3. Methodological approach

Based on Liu et al. (2017)s' suggestion for strengthening discussions and interpretations of the WECC nexus configurations based on both physical and social measurements[3], the current study employed a quantitative approach using secondary data obtained from different

[3] Physical measurement refers to the elements such as statistical data while social measurement is more about perspectives of the stakeholders, etc.

stakeholders[4] to analyse the interfaces between the water-energy, energy-water, energy-climate change and climate change-water elements in South Africa. The data, collected by the stakeholders between December 2018 and July 2019, predominantly focus on the regions of Highveld and Waterberg. The choice of the two regions is informed by the fact that, despite experiencing freshwater challenges such as limited quantities and poor quality, they play a central role in the energy generation sector by housing 10 coal-fired power stations which, in turn, contribute significantly towards the country's GHG emissions. A purposeful sampling method complemented by the snowball technique was used in identifying data sources. It was important to use this purposeful random sampling method because the study speciality needed to identify and engage with people that are responsible for the management of such data in different organisations as illustrated in Table 3.1.

Table 3.1: Sources of raw data

Organisation	Role in WECC nexus	Data Format	Data verification process
Eskom	Owns and operates power plants in South Africa to ensure electricity supply	>.Xls (spreadsheet) on water consumption vs energy produced 2008-2018 >.link to GHG emissions 2008-2018	Eskom internal and external verification processes such as audits
South African Weather Services (SAWS)	Operation of weather stations countrywide in ensuring the provision of climate services	>.Xls (spreadsheet) on Witbank and Lephalale rainfall versus temperature 2008-2018	SAWS internal procedure on the maintenance of measuring equipment and software

Source: Based on fieldwork: 2019

In terms of data analysis, the study employed a rapid appraisal technique coupled with meta-analysis. The rapid analysis involved a critical analysis of the whole data set while identifying only the information that is of value to the topic under investigation. Whereas the meta-analysis technique involved an analysis of the statistical data obtained from different sources. The data

[4] These include Eskom, South African Weather Services, and Department of Environmental Affairs

from this process was progressively converted into different graphs such as bar charts and trends to establish certain correlations.

3.4. Results and discussions

This section summarises outcomes of the identified points at which WECC components interact in South Africa, particularly emphasizing on coupled water-energy interface, energy contribution towards climate change and climate change influence in water resources. The main issues highlighted in these presentations also address challenges South Africa must overcome to progress towards achieving sustainable management of WECC particularly from the water resource management point of view and to convert data into an information tool used for critical decision-making process both in the private and public sector.

3.4.1. Coupled water-energy interchange

The first outcome of this study validates the inextricable interdependency of South Africa's water and energy supply systems on each other. Water is seen as an indispensable raw material towards energy generation. Carpenter (2015), for example, asserts that the majority of the energy-related water withdrawals are for energy generation and approximately 75% of those are specifically for electricity production. In South Africa, the water-intense coal-combustion process is the most reliable energy source as it contributes approximately 85% of the electricity generated in the country. This observation, therefore, declares that freshwater input towards South Africa's power plants is a requisite. Exemplifying this assertion, Figure 3.1 illustrates the indispensable role that water plays in the country's electricity generation system. This (Figure 3.1) is drawn from the data collected by Eskom from the coal-combustion power plants located at the Highveld and Waterberg regions. The power plants in these regions contribute approximately 32000 Megawatt (MW) of the country's 45000 MW installed capacity. Moreover, the graph (Figure 3.1) draws a comparison of the amount of water in litres (*l*) used to produce Kilowatt per hour Send Out (*KWhSO*) electricity from each region between the years 2008 to 2018.

From Figure 3.1, it is evident that the power plants within the Highveld consume more water than those in the Waterberg. In 2008, for example, 3.5*l* was consumed by the Highveld power plants to generate 1*KWhSO* as compared to 0.1 *l/KWhSO* used by those in the Waterberg. On average, Highveld power plants utilised 2 *l/KWh*SO more than those in the Waterberg over the 11 years recording period. This is influenced by the decreased generation capacity at the

Highveld between 2008 and 2010, while this has increased in the Waterberg between 2014 and 2016. For example, Eskom (2019) highlights additional and reduction of generating units between 2008 and 2011 as a contributing factor towards these varying water consumptions. While Figure 3.1 highlights the significant role of water towards electricity generation, the quantity required is influenced by several factors. Firstly, it is influenced by the capacity of power plants. For example, the power plants in the Highveld have an installed capacity of approximately 24000MW as compared to the 8000MW in the Waterberg, therefore, they use more water in their processes. Secondly, the technology applied in each power plant. Despite both technologies being water-dependent, all power plants in the Waterberg employs a dry-cooled process in contrast to 6 of the 8 stations in the Highveld. This observation supports assertions by Pather (2004) and Cullis et al. (2018) that the dry-cooling process uses approximately 15% less water than the wet-cooling. Furthermore, Pather (2004) and DWS (2014) concurred that the significant yet high water demands in the coal-combustion electricity generation process drove the country to resolve to partial and fully dry-cooling technology in their post-1980 power plants.

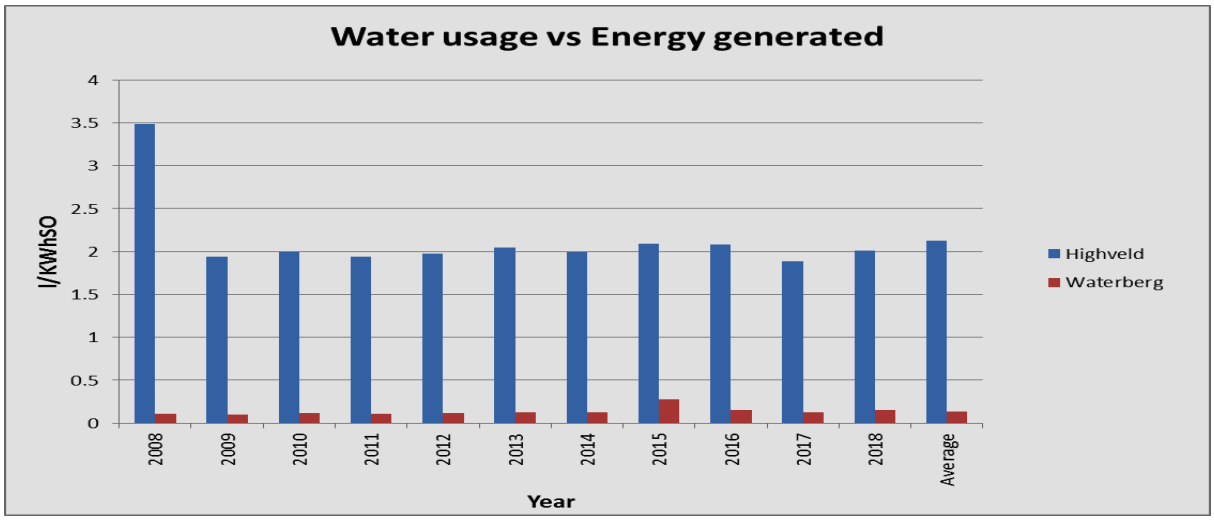


Figure 3.1: Water used per Kilowatt per hour Sent Out for the Highveld and Waterberg stations
Source of raw data: Eskom (2019)

The above deliberations demonstrate that, despite the energy sector being considered a "strategic water user" with a 2% freshwater allocation at a high assurance, it remains vulnerable due to the finite status of water resources in the country. Efforts to maintain supply are done through continual importing of approximately 90% of fresh water for energy generation from the Usuthu, Vaal and Inkomati catchments to the power plants in the Highveld region. Also, as

there are projected increases for water withdrawals in the energy sector, South Africa, prompted by persistent water deterioration in the country, has driven the development of schemes such as the Lesotho Highlands Water Project Phase 2, Nkomati, and Mokolo-Crocodile Augmentation Projects. These initiatives are implemented to substantiate water supply to the energy and other socio-economic sectors such as agriculture. Moreover, the proportions in Figure 3.1 highlight the significance of data towards the quantification of water requirements for energy generation, a critical factor in the planning of these constrained resources.

Similar to the above observations, the role of energy towards water systems is equally important. This is stressed across the globe with other countries such as the US and Australia having effectively quantified the energy needed for their water supply value chains (abstraction, treatment, and distribution) to inform the planning processes (Cammerman, 2009; Carpenter, 2015). Besides, Gobin et al. (2019) contended that approximately 2-3% of the global energy produced is consumed through the water supply systems and in South Africa; this consumption is the third-largest electricity usage. This argument is supported by the South African Cities Network (2014) who observed the increasing need for energy towards the water and wastewater treatment driven mainly by rising population, industrialisation and urbanisation. Moreover, the distanced geographical locations between intended users and water sources aggravate energy demands (Cullis et al., 2018). Furthermore, the increasing population coupled with industrialisation and urbanisation has resulted in increased water pollution thus requiring efficient treatment.

Given the above arguments, it is observed that the effective management of energy towards water provision requires the availability of reliable data that is easily accessible by all stakeholders involved in this interrelation between these two systems. However, in South Africa, data availability and accessibility are hampered by institutional frameworks that operate in the “silo” system. This, therefore, creates a scenario where institutions make policies and strategies that are not aligned with one another and resulting in deficiencies towards decision-making processes regarding the management of energy and water resources. For example, this study revealed a lack of cooperation in terms of data sharing among different systems and operations mandated to ensure water and energy supply. This observation support Liu et al. (2017)’s argument that information related to energy usage in the water value chain can be

difficult to obtain therefore making it impossible to quantify the energy needed for water provision in South Africa.

3.4.2. The energy sectors' contribution to GHG emissions

The second scenario highlights the influence of the country's energy system towards GHG emissions thus elevating climate change. Contribution of the energy sector particularly from the coal-combustion process towards climate change is a global challenge (Intergovernmental Panel on Climate Change, 2014). In South Africa, for example, this coal-combustion process is currently the most reliable source of the country's energy and the main source of the GHGs (Seymore et al., 2014; Cullis et al., 2018). To elaborate this observation, Figure 3.2 shows the amount of Carbon dioxide (CO_2) and Nitrous oxide (N_2O) emitted from Eskom's coal-fired power plants, with marginal contribution from the Open Cycle Gas Turbines (OCGT). The figure is based on the data collected and reported by Eskom from 2008 to 2018. The difference in the contribution is attributed to coal power plants' ability to produce more GHGs as compared to OCGT as well as the frequency of usage between these electricity sources. Eskom (2019) states that OCTG usage is minimal and mainly occurs during electricity shortages from coal power plants.

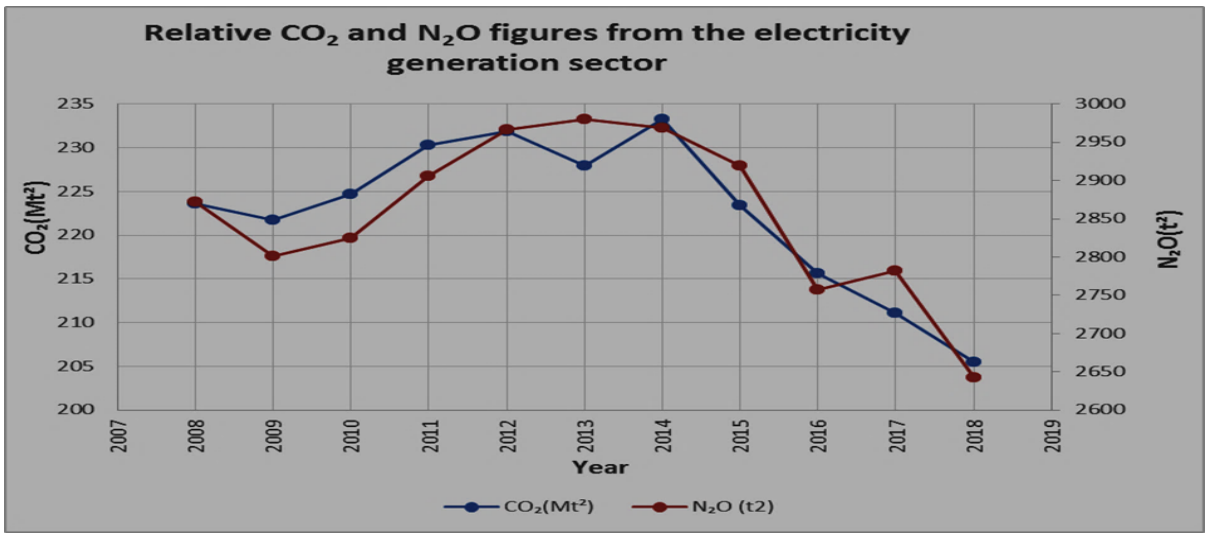


Figure 3.2: Relative CO_2 and N_2O produced during electricity generation
Source of raw data: Eskom (2019)

The contention from DEA (2015) that the CO_2 emissions in the country are largely due to contributions from the energy sector is evident by the release of an average of 223 Mt^2 CO_2 from 2008 to 2018 with the highest concentrations of 233 Mt^2 recorded in 2014. However, a decrease in the CO_2 emitted is observed from 2014 to 2018. This corresponds with the

observation of a 0.04% decline in the CO_2 recorded from the energy sector since 2012 (DEA, 2015). Similarly, higher concentrations of N_2O are emitted from this sector. For example, it is observed in this graph that the average N_2O concentrations released from the electricity sector are 2865 t^2 with the highest recorded figure of 2980 t^2 in 2013. These observations intensify the need to acknowledge the contribution of the country's energy sector towards the GHGs. The decline in the releases of the CO_2 and N_2O, however, is an indication of the increased effort in managing these gases, and this could be attributed to the improved awareness of climate change impact on natural and socioeconomic factors particularly the already constrained water resources. For instance, the strengthening of GHG emissions legislation resulted in retrofitting of emission plants and improvement in the reporting systems on these gases. However, there is an intensified need to further develop and strengthen resilience and adaptive strategies such as regulatory framework, technological and analytical tools to assist in making informed decisions regarding the reduction of GHG emissions.

3.4.3. Influence of climate change on water resources

The last outcome highlights the role of climate change towards the country's finite water resources. Temperature variabilities are known to be the key driver towards the hydrological cycle, thus influencing water availability. In South Africa, for example, Nkhonjera (2017) argued that climate change-related aspects such as prolonged droughts, floods, and intensified rainfall are already showing. Based on the data acquired from SAWS, Figure 3.3 draws the linkages of varying temperatures and rainfall intensities within the Highveld and Waterberg regions. In comparing the annual temperature between the two regions, it is evident that Waterberg experiences a higher and more inconstant temperature than the Highveld. For example, this region recorded a highly fluctuating temperature for two reporting periods of 2009-2011 and 2014-2017 while the Highveld remain mainly constant throughout 2008-2018. These recorded temperature levels support an observation that Waterberg is one of those regions in the country that are expected to warm significantly as a result of climate change (Eskom, 2012).

Also, what is evident in Figure 3.3 is the varying rainfall patterns in each region and how it is influenced by temperature. For example, the Highveld region recorded lower temperatures and high, varying rainfall patterns in contrary to the higher temperatures and lower, constant rainfall of the Waterberg region. The average rainfall in each of these regions, however, remains lower than the country's annual average of 495mm. This observation is supported by Mukheibir

(2008) who argued that the temperature of the Inland is expected to increase by approximately 2-3^{o}C as compared to the 1.5^{o}C in the Coastal areas thus lowering the region's precipitation intensity, frequency, and duration. It is therefore argued that these unpredictable, variations, and increased rainfall intensities, resulting from the projected global warming, will exert pressure on the country's already constrained water resources. This supports the views of Eskom (2012) and Nkhonjera (2017) that climate variabilities in the Waterberg and Highveld regions will intensify the increasing water demands for Oliphants and Mokolo catchments thus impacting on both ecological and socio-economic activities predominantly energy and agriculture.

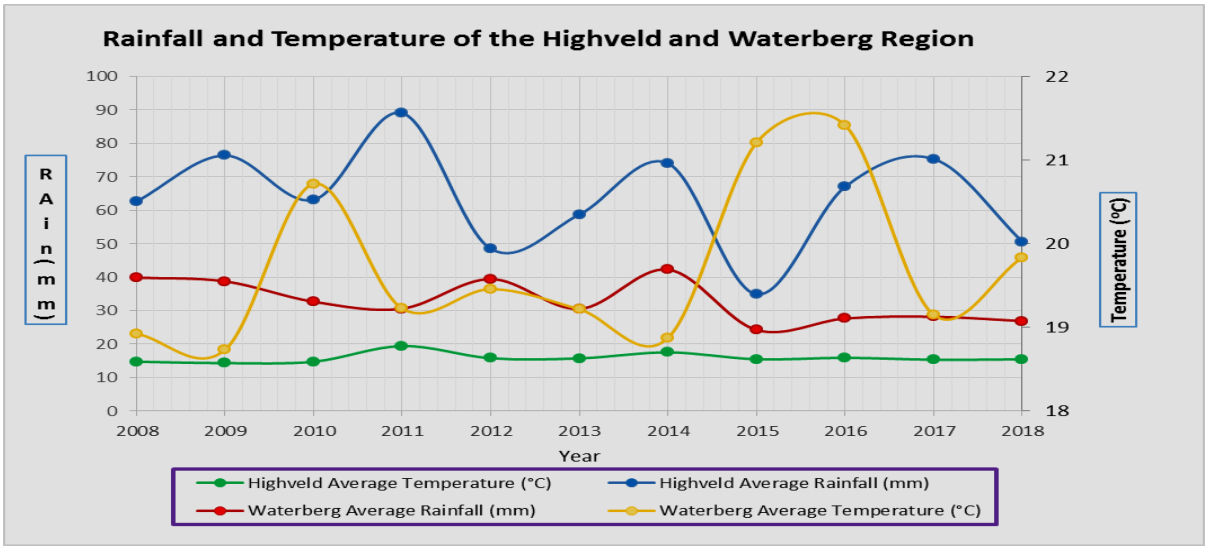


Figure 3.3: Comparison of the temperature and rainfall interactions
Source of raw data: SAWS

3.5. Conclusions and recommendations

The interaction between water, energy and climate change in South Africa is unavoidable, resulting in WECC nexus. This nexus, therefore, needs to be managed effectively to mitigate its influence of water and energy security while combating climate change. The following findings emanated from this study. Firstly, the dire status of water in the country could act as a motivation for South Africa to manage this nexus configuration from the water resource perspective. This could be done with the acknowledgement of water as a finite and indispensable resource cross-cutting many socio-economic activities such as energy. Secondly, data plays a crucial role in the quantification and understanding of the WECC interlinkages. It should, therefore, be accessible, reliable and of good quality so that it can inform policy-makers and relevant stakeholders in making critical decisions across all sectors. The study, however,

revealed a lack of systems to ensure data availability and accessibility across different stakeholders. This was evidenced particularly in the energy for water provision scenario where it was difficult to obtain data due to challenges revolving around red-tape and in some instances the lack of data.

While South Africa looks into holistic and integration prospects of effectively managing the WECC, this study provides the following recommendations. Firstly, the study presents the country with an opportunity to revise its system thinking in data management. Therefore new endeavours such as digitalisation and regulatory frameworks should be developed to intensify data capturing, accessibility and reliability. Secondly, the country's policy development should be drafted based on the information derived from the data. This could assist policy-makers in making informed decisions on strategies within water, energy and climate change sectors. Furthermore, the country should initiate policy integration to ensure that this nexus is addressed holistically. Until such systems and processes are put in place the WECC nexus will continue hampering national development and socio-economic growth.

CHAPTER FOUR

Application of the participatory approach as an analytical framework for understanding the Water-Energy-Climate Change Nexus in South Africa[5]

ABSTRACT

This study uses a Participatory Approach (PA) to assess the potential of this framework in facilitating the development of well-coordinated, systematic and holistic strategies and approaches for the management of the Water-Energy-Climate Change (WECC) nexus and associated implications in South Africa. This is assessed within the broader context of the Integrated Water Resource Management principle, which promotes a PA in the administration of water resources. It is argued in the study that, despite the reasonable level of acknowledgement and understanding of WECC, there is still a lack of integrated policy development which is exacerbated by limited coordination and consultation among key stakeholders. Thus, the current state of affairs requires the adoption of holistic and system thinking approaches. This could be attained through the promotion of increased collaboration among different stakeholders mandated to manage WECC challenges. Until such approaches are adopted, the WECC nexus will continue to impede the country's socio-economic development and environmental wellbeing.

Keywords: participatory approach, WECC nexus, South Africa, integrated water resource management, collaboration

4.1. Introduction

The emergence of climate change and its overarching role on water and energy resources has intensified the need for investigating the Water-Energy-Climate Change (WECC) nexus (Cammerman, 2009; Head and Cammerman, 2010; Mathetsa et al., 2019). This call is prompted mainly by the repercussions of the WECC nexus on the Sustainable Development

[5] This chapter is based on: Mathetsa, S.M., Simatele, M.D., Rampedi, I.T. and Gericke, G. 2019. Application of participatory approach as an analytical framework for Water-Energy-Climate Change nexus in South Africa. **International Journal of Environment and Sustainable Development** (Peer Review-First draft).

Goals (SDGs). It is argued that the complex interconnection between these three components necessitates a "nexus thinking" approach, which recommends holistic and integrated management of the WECC (Mukheibir, 2008; Cullis et al., 2018; Mathetsa et al., 2019). Several aspects, however, indicate that the risks associated with this nexus have not been fully captured on a global scale. Hence, the sectoral decision-making model is of limited value in understanding the ramifications within the WECC nexus (Aboelgna et al., 2018; Brasilia et al., 2008; Hussey and Pittock, 2012; Liu et al., 2017). This continued fragmentation reveals a lack of urgency in integrating the management of this nexus, an observation mainly experienced in poor and middle-income countries. In Sub-Saharan Africa (SSA) region, the lack of a conceptual framework for understanding this nexus is at an all-time high, especially because of existing challenges such as water scarcity, growing energy demand and lack of effective systems to deal with climate change impacts (Cullis et al., 2008; Mathetsa et al., 2019). Failure to recognise this "nexus thinking" has long term implications on the welfare of affected communities which are predominantly poor and vulnerable.

Similar to international developments, South Africa is confronted with a lack of integrated approaches to manage different nexus configurations such as the WECC complex (Mabhaudhi et al., 2016; Nhamo et al., 2018; Prasad et al., 2012). This is demonstrated by the continued fragmented approach in the planning and development of policies and strategies aimed at addressing increasing water, energy and climate change challenges in the country (Gobin et al., 2019; Mathetsa et al., 2019). This observation, coupled with a lack of urgency in the implementation of proposed mitigation measures, suggests that there are limited coordination and collaboration approach among key stakeholders such as researchers, policy-makers and communities. Such limited interaction amongst these stakeholders intensifies the need to develop contemporary measures to comprehend the WECC while promoting "nexus thinking" in South Africa.

One of the prospects suggested by Cammerman (2009) is to manage the WECC nexus from the water-centric perspective. This approach is feasible for countries such as South Africa as they are confronted with a dire water status. Furthermore, Cammerman (2009) and Cammerman and Head (2010) are of the view that the Integrated Water Resource Management (IWRM) framework, one of the useful tools in facilitating sustainable water management, can be effective in managing complex systems such as this nexus. This framework's effective implementation is based on four principles. One of these principles is the participatory

approach (PA) which advocates for a collaborated and informed decision-making process within the water resource management systems and related activities such as land use (Aboelgna et al., 2018; Flammini, 2014; Global Water Partnership [GWP], 2000). With the "nexus thinking", Hoolohan et al. (2018) argued that engagement of stakeholders is pivotal in bringing together actors from different spectrums to holistically promote the management of different nexus configurations such as WECC. Moreover, engaging key stakeholders has the potential to promote an effective decision-making process which is based on a common understanding of the complexity and challenges brought by the nexus.

Given the implications of WECC on the achievement of South Africa's SDGs, it is not unreasonable to suggest that more integrated approaches are needed to understand and inform decision-making processes in support of this nexus. This study explores the extent to which the PA can be used as an analytical framework to assess WECC and improve the management of this nexus in South Africa. Different techniques are used to examine the stakeholders' perceptions of this nexus and gather suggestions on the development of resilient systems. The study provides a brief appraisal of developments on the PA as a profound tool vital in the management of complex systems such as water resources and nexus configurations. Of particular importance in this study is examining the importance of the PA in mitigating the impacts of the WECC nexus on all subsectors of the economy in South Africa.

4.2. An appraisal of the upsurge of the participatory approach as a decision-making tool

The PA, which is also referred to as "stakeholder engagement" or "public participation" is not a new method in research or policy discussions. Studies focusing on the PA as a method of addressing complex development issues affecting broader issues in societies have over the years identified it as an important tool in critical decision-making processes. Chambers (1994), for example, expressed the view that the PA advocates for the participation of various stakeholders on issues where their welfare is of concern (Also see Babooa, 2008; Nyathi, 2008; Legislative Sector Support [LSS], 2013). The advancement of this approach, mainly in democratic societies, seeks to involve more local people in policy planning and implementation, thus enabling the utilisation of indigenous knowledge in the development of tools to manage emerging societal needs (Alam and Ihsan, 2012; Dungumaru and Madulu, 2003). The potential of this approach lies in its ability to enable communication and an inclusive decision-making process which allows for the consideration of views expressed by various stakeholders. The approach is commended by Barreteau et al. (2013) for its ability to

stimulate social cohesions thus consequently prompting decisions to be made based on the realities and situations that affect broader communities. Also, Barbosa et al. (2017) are of the view that the PA is critical as it promotes inclusive decision-making that ensures that the outcomes of a particular decision are of acceptable quality.

Despite global debates on the importance and value of stakeholder engagement in facilitating socio-economic transformations as well as improved environmental wellbeing, the top-down approach still dominates the decision-making landscape in many societies, particularly in the SSA region (see Kubanza and Simatele 2019). In most cases, the top-down systems are dominated by decisions taken or made by powerful and influential players before the consultation process or without profoundly considering the views of the communities at the grassroots level (Chambers, 1994; GWP, 2000). The lack of meaningful engagements with stakeholders mainly results in conflicts or contradictions particularly during the implementation stages of the decision made. For instance, Nyathi (2008) is of the view that several local decisions such as municipal demarcations in South Africa are often met with conflicts as, in most cases, local communities perceive that the correct consultation processes of inclusive decision-making or their considerations are not considered by the authorities.

In the context of SSA, Denby et al. (2016) are of the view that the region lacks behind in applying participatory approaches as a tool for the development of projects or policies. Fatch (2009), Mathekga and Buccus (2006), and Prinsloo (2008) have associated this ineffective application of the PA with factors such as limited understanding of project contextualization and resource constraints (i.e. financial) prevailing within the local and marginalized communities. These limitations have, however, not prevented countries such as South Africa from persuading the advancement of the widened stakeholder participation within its critical systems such as policy development. For instance, the proclamation of Section 195(1) (e) in the country's constitution, which mandates the development of policies and strategies within the reach of public comments, is an example of the endorsement of this approach (Nyathi, 2008; The Constitution of the Republic of South Africa, 2005). This encourages the involvement of key stakeholders including the marginalised communities with an opportunity to share their knowledge and understanding and thus assisting policy-makers to be aware of the issues from a broadened perspective. Also, these developments have prompted several resource-management policies such as the National Environmental Management Act (i.e. Act no 107 of 1998) and the National Water Act (Act no 36 of 1998) to adopt stakeholder

consultation as part of the decision-making process before issuance of permits (Department of Environmental Affairs, 1998; Department of Water Affairs (DWS), 1998). From a legislative and policy perspective, South Africa, especially in the environmental management space, has made tremendous progress although concerns about policy and strategy implementation remain untested.

4.2.1. Towards a participatory approach in the management of WECC nexus

The growing need to adopt the PA within sustainable development issues is driven by the rapid development of new and complex challenges that cannot be addressed from a segmented or sectoral perspective. The mounting challenge associated with water resource management is one example which has persuaded international communities to recognize the importance of stakeholder participation, resulting in the endorsement of the IWRM framework, which is centred on the participation of country-specific (local communities) and international actors, as one of its main principles (GWP, 2000; Suhardiman et al., 2015). Several studies have acknowledged that the application of the PA is vital as it enables the development of inclusive strategies and institutional frameworks such as Catchment Management Agencies (CMA) within a particular catchment or basin intending to strengthen sustainable water resource management systems (Butt et al., 2005; Du Toit and Pollard, 2008; DWS, 2013; Jingling et al., 2010; Rahaman, 2004). The PA can bring key role players such as planners, users, service providers, policy-makers, research experts, and local communities together to engage, raise concerns or suggestions, and share the knowledge to promote equitable and sustainable usage of water resources within a specific catchment. In the SSA, Madzungu (2004) pointed out that the PA's potential to promote the inclusive decision-making processes in water resource management has prompted many regional countries to adopt this approach in facilitating collaboration and coordinated development of solutions to challenges.

Despite its ability to influence water resource management positively, limiting factors such as political will, lack of skills and technical know-how as well as financial implications continue to hamper the effective implementation of the PA. For instance, Biswas (2008) and Suhardiman et al. (2015) are of the view that lack of political will to develop policies based on wider stakeholder consultation has resulted in failures to ensure that there is an inclusive decision-making process to recognise the importance of the PA in some global communities. Furthermore, Cheru (2002) observes that a lack of effective political leadership has done more

harm to kill the spirit of grassroots ingenuity in natural resource management and community involvement. In South Africa, however, developments are underway to ensure that PA-aligned strategies are established to encourage the involvement of all key actors, particularly the marginalised (Nyathi, 2008; LSS, 2013). For instance, DWS (2013) and Karar (2008) are of the view that the successful establishment of the institutional frameworks and policies such as CMAs and National Water Resource Strategy (NWRS) presents efforts made to align policy development within water resources with considerations of the local communities.

While sustainable water resource management is embedded on a common understanding and coordinated approach between policy-makers and other key stakeholders (Suhardiman et al., 2015; World Economic Forum [WEF], 2011), it necessitates the need for a similar view in the promotion of the "nexus thinking". The successful implementation of PA within the water resource management suggests that this approach can also be effective in the assessment of the water-linked nexus systems such as WECC. For instance, Aboelgna et al. (2018) and Hoolohan et al. (2018) are of the view that the use of a PA in addressing complex configurations such as nexus has the potential to promote "nexus thinking" in a manner that equally addresses the linked systems. Also, recent developments reveal that PA has proven to be effective in addressing the three-legged Water-Energy-Food nexus through the assessment of the perspectives of key sectors from natural science, social science, and humanities (Endo, 2015; Wicaksono et al., 2017). In the context of WECC, which continues to bring challenges to communities and how they respond to it, Aboelgna et al. (2018) and Cammerman (2009) observes that a PA that promotes collaboration and multi-stakeholder approach of this nexus is an absolute imperative. The application of PA in the WECC is persuaded by the need to fill the knowledge gap between stakeholders and address socio-economic and environmental challenges arising within different communities.

Regardless of the intents of PA to strengthen awareness, broaden understanding, and promote integrated and holistic management of WECC, there are still exclusions and ineffective consultation within the assessment of this nexus. These shortfalls are predominantly observed through a lack of policy alignment and prevailing sectoral mandates between the three sectors of water, energy and climate change (Hoolohan et al., 2018; United States Department of Energy [US DoE], 2014; Wicaksono et al., 2017). In other countries such as Argentina and Kenya, this lack of acknowledgement of PA systems has resulted in failures to consider geographical locations, community preferences and exclusion of marginalised societies in the

implementation of WECC-efficient projects such as renewable energy water pumping systems (Platonova and Leone, 2012). In this instance, critical decisions are bound to be made without full knowledge of local characteristics or proper stakeholder involvement.

While South Africa is experiencing climate change at various scales, there is a rising demand for freshwater and energy resources. However, one of the critical challenges dominating its decision-making process is a top-down approach aggravated by the political and socio-economic pressure to meet the demand in service delivery (Wicaksono et al., 2017). This suggests that the need to apply PA, where stakeholders' welfare is of great concern, is not effectively being adhered to. This is despite the constitutional mandate to ensure that key sectors such as government departments, local communities, industries, experts and researchers are consulted to provide a meaningful, well-informed and effective policy instruments within the sectors of water, energy, and climate change. The widely reported sectoral mandated policies, instigated by the prevailing lack of coordinated and integrated approaches (Godin et al., 2019; Mabhaudhi et al., 2016; Mathetsa et al., 2019; Nhamo et al., 2018), demonstrates this lack of implementation of the PA. These observations suggest that the effectiveness of WECC management and the promotion of awareness, knowledge-sharing and informed policy development can be comprehended through the discussion of this nexus within the discourse of appropriate stakeholder engagement, thus the application of the PA.

4.3. Methodological consideration

This study is based on a qualitative approach which, according to Charmaz (2013) and Van Zyl (2014), focusses more on assessing human perceptions and behaviours concerning the study of interest. The study of this nature collects data by engaging with participants mainly through interviews (Denscombe, 2003). A Grounded Theory (GT) was adopted as a methodological and analytical approach for this study. Leady and Ormond (2013) view the GT as a research approach that focuses mainly on developing a theory from the collected data. Also, this method was selected due to its ability to apply both the deductive and inductive approaches (Charmaz, 2013). However, an inductive approach of the GT was preferred in this study as its systematic approach of data condensation offers simplified, reliable and valid findings thus resulting in a constructive theory on the status of the nexus (Mills et al., 2006; Thomas, 2006).

In selecting research participants, a non-probability sampling approach was used. In this approach, the likelihood or probability of selecting the targeted population is not known (Van

Zyl, 2014). In this study, this approach allowed for the purposive and snowball techniques to be used in the selection and engagement with the targeted population. These two techniques(i.e. snowball and purposive) were selected as they are crucial in the identification and selection of individuals, groups or organizations that have the experience and educational qualifications relevant to support the substantive arguments thus providing information or data necessary to attain study objectives (Kirchherr and Charles, 2018; Tongco, 2007). These approaches resulted in the selection of policy-makers within government (i.e. national government departments), local government (i.e. municipalities), energy and water utilities or agencies, Non-Governmental Organizations (NGOs), and academic and research experts. These research participants are illustrated in Table 4.1. Validation of the participants' experience was done through the number of years they were involved in the respective sectors. A total of seven (7) focus group discussions and eight (8) one-on-one interviews were held from the 30th of August to the 10th of October 2019. The engagements were conducted through personal communication with the research participants using a semi-structured questionnaire which was drafted following the examples of European Corporation for Science and Technology [COST] (2009) and Head and Cammerman (2010). The semi-structured questionnaire was organized in four themes being demographic characteristics; assessment of the level of understanding of the WECC, determination of the stakeholders' perspectives on collaboration and coordination, and policy development processes.

Furthermore, a telephonic conversation was held with a regional specialist who shared his opinions on the WECC from the SSA perspective. Also, another data collection technique used is the participants' observation, which Dawson (2002) and Kawulich (2005) view as a tool where the behaviour of participants is being observed during the discussion of the subject matter under study. This technique was applied at a workshop held on the 07th-08th October 2019 arranged by the DMRE and attended by 45 stakeholders representing different government sectors and relevant water, energy and climate change agencies. Responses from 14 participants who presented on various topics, however, were mainly used for assessment of this study. This workshop aimed to discuss progress on energy efficiencies and renewable energy within the government infrastructure in the country. Relevant protocols such as permission to conduct this observation and informing the workshop attendees of this process were obtained prior.

Engagements with participants were used to formulate responses to the selected themes. The research participants were given pseudonyms to protect their identity. The responses of the participants were captured through an audio recorder and field notes transcribed verbatim and kept in their original form. Each transcript was given a code for clear identification immediately after the interview. The data were analysed through both the phenomenological and content analysis. These methods involve a systematic analysis of responses from the research participants using a GT (Bless et al., 2013). This approach has the ability to creating conceptual frameworks from discussions by building instructive analysis from the data (Charmaz, 2013). Also, a constant comparison, which highlighted similarities in the responses, was used to analyse and transmute the outlined themes into findings and observations (Charmaz, 2013).

Table 4.1: Profile of research respondents

Pseudonym	Organisation	Number of participants	Combined years of experience	Highest level of Education
WECC-A	Department of Environment, Forestry, and Fishery (DEFF)	3	41	Postgraduate
WECC-B1	Department of Water, Sanitation and Human Settlement (DWSHS)	4	64	Postgraduate
WECC-B2	DWSHS	2	47	Postgraduate
WECC-D1	Energy –Eskom	3	60	Postgraduate
WECC-D2	Energy – Eskom	2	28	Postgraduate
WECC-D3	Energy – Eskom	3	80	Postgraduate
WECC-E	Water services – Rand Water	2	22	Postgraduate
WECC-F	Research and governance-Eskom	1	32	Postgraduate
WECC-G	Research and Academia – Water	1	45	Postgraduate
WECC-H	Private–Climate Change Consultant	1	10	Postgraduate
WECC-I	Research – Climate Change	1	20	Postgraduate

WECC-J	Non-Governmental Organizations (NGO)	2	39	Postgraduate
WECC-K	Research Agency – Energy	2	28	Postgraduate
WECC-M	Local government – Tshwane Municipality	1	24	Postgraduate
WECC-L	Research and Academia: Regional	1	20	Postgraduate
WECC-C	Department of Mineral Resources and Energy (DMRE) workshop	14	Approximately 200	Postgraduate

Source: Based on field surveys (2019)

4.4. Results and Discussions

This section presents the outcomes of assessments of some key features (i.e. understanding, policy development, and collaboration) that promote the holistic management of the WECC nexus in the context of South Africa. This is vital in the strengthening of the development of a policy framework that drives efficiencies in the water and energy supply while addressing the growing climate change concerns in the country.

4.4.1. Key stakeholders' perceptions of WECC in South Africa

This sub-section presents the perceptions of the research participants on the understanding of the WECC in South Africa. Hoolohan et al. (2017), for example, are of the view that the understanding of the nexus can be determined by assessing the perspectives of stakeholders hence it was important for this study to obtain the diverse perceptions of these participants. This was done to determine the extent to which the interconnection between these components is embraced within the nexus in South Africa. The assessment was conducted through responses from 43 research participants drawn from engagement with 16 organisations and subject matter experts within the water, energy and climate change sectors (See Table 4.1). The grouping and analysis of perspectives from these participants are illustrated in Table 4.2.

Table 4.2: Perceptions of the research participants on WECC nexus in South Africa

Coupled WECC interconnection	Number of responses	Percentage (%)
Water-Energy-Climate Change	18	42
Water-Energy	13	30
Water-Climate Change	9	21
Climate Change-Energy	3	7
Total number of engagements	43	100

Source: Based on field surveys (2019)

The responses indicate that 42% of the research participants were able to demonstrate that they have sufficient knowledge of the WECC interconnections in its entirety. This means that the research participants illustrated how equally the water, energy, and climate change components interact. For instance, one response which entirely illustrated completeness on how this nexus is understood was from respondent WECC-B_1 who stated that:

> "*The country's electricity generation system heavily relies on water supply, which its availability is negatively influenced by extreme climate conditions. On the other hand, these climate conditions are exacerbated by the dominant energy production technologies, particularly coal-combustion. Also, the consequences of climate change impact the country's energy generation systems" (Personal Communication: Focus group discussion on the 19th of September 2019).*

On the other hand, the majority (i.e. 58%) of the responses indicate that the perceptions or knowledge of the research participants on the WECC is still sectorally-based. For instance, 30% of the participants, who operate mainly within the water and energy sectors, did not acknowledge the linkage or implications of climate change on the water and energy resources. These perceptions validate the findings of other studies in South Africa which argued that the understanding of the nexus is dominated by sectoral boundaries (Mabhaudhi et al. 2016; Mathetsa et al., 2019). These responses unravel some of the basic reasoning behind the prevailing "silo" approach in the planning and development of policies by key departments mandated to manage the water, energy and climate change sectors. This is amidst the call for the sectors of water, energy and climate change to be managed in a holistic and integrated manner (Cullis et al., 2018; Mukheibir, 2008). The empirical findings from this study reveal a lack of common consensus on how WECC elements are interlinked in South Africa. These

outcomes concur with those of Head and Cammerman (2010) and Liu (2018) who are of the view that global communities are challenged with the prevailing limited mutual understanding of the WECC nexus interactions, thus limiting their ability to comprehensively analyse this nexus. Based on these observations, it is argued that the sectoral-based understanding results in inefficiencies to promote the WECC "nexus thinking" in South Africa.

Amidst the lack of mutual understanding of the WECC interactions in South Africa, research participant WECC-L observed that, as compared to other SSA countries, "*South Africa has elaborated significant progress in understanding and analysing the nexus that involves water, energy, food, and climate change" (Personal Communication: a telephonic conversation with Yillia, P.T. on 8th October 2019).* This is corroborated by several initiatives such as technology (i.e. dry-cooling, emission abatement, renewable energy, and carbon capture) and strategies (i.e. National Water Resource Strategy, National Climate Change Response Strategy, Renewable Energy Independent Power Producers) being developed and implemented in the country. Furthermore, WECC-D_1, WECC-D_2, WECC-D_3, and WECC-E mentioned these interventions as a means to demonstrate the attention that WECC is receiving both at an operational and planning phase in the country. To support this view, the discussion efforts such as the WECC-Cs' workshop (see Table 4.1) also highlight an initiative to promote a multistakeholder awareness and understanding of this nexus. These developments are relevant in the current landscape as there is a need for the country to identify and develop potential ways to shape and promote a framework for a common understanding of the country's WECC status.

The information gathered from the research participants demonstrates the ability of the PA to support the unravelling of some of the prevailing WECC challenges such as limited understanding and fragmented decision-making within the nexus system in South Africa. For example, it was pre-assumed that, based on the experience and educational qualifications, the research participants would demonstrate clearly how WECC elements are interlinked. However, the responses reflect a not-so-clear understanding of the converse linkages. This is most evident in the manner in which some of the core elements of PA (i.e. knowledge-sharing, and awareness), were presented and perceived amongst the research participants. This consequently provides the country with an opportunity to promote awareness and communication among key WECC sectors within which the understanding of this nexus configuration can be strengthened across society at large. This assessment further encourages the focus on the relevancy of the "nexus thinking" in the development of mitigation measures

and resilient systems to address the shortfalls emanating from the WECC (Aboelgna et al., 2018; Gulati et al., 2013).

4.4.2. Collaboration and coordination as a means to implement WECC in South Africa

Within the water resource management, the intensified need for coordination and collaboration is driven by the shared river basins and dire water status of most international communities (Barbosa, 2017; GWP, 2000; Pollard and Du Toit, 2008). Similarly, Head and Cammerman (2010) and US DoE (2014) pointed out that coordination and collaboration across all the levels of WECC are important as they raise opportunities for effective resource management and allocation processes such as water transfer schemes, energy exports, and climate change accords. Furthermore, collaboration enables the sharing of resources, data, and information relevant to address the interconnections between water, energy and climate change. In the Southern African region and South Africa particularly, significant collaboration is required among water, energy, and climate change managers to tackle the WECC nexus challenges.

This sub-section follows the suggestions of Bizikova et al. (2013) and Wicaksono (2017) that coordination and collaboration within WECC can be assessed and promoted through the engagement of stakeholders. One of the key elements defining this study is assessing the research participants' views on the level of coordination and collaboration among various WECC stakeholders in the country. Table 4.3 illustrates the views of different research participants on the effectiveness of current coordination and collaboration efforts in the country's WECC position. These views are grouped according to the organisational affiliation of the participants.

Table 4.3: Views on the coordination and collaboration of WECC among research participants in South Africa

Organisation\Sector	Are the current coordination and collaboration efforts effective to address WECC challenges?	How can coordination and collaboration be improved?
Department of DWSHS	Partially yes. Initiates liaison with different role players to develop policies and measures to address water challenges and their association with the energy and climate change sector.	Promote the political will to adopt views from experts. Implement institutional mechanisms that are similar to those in IWRM. E.g. CMA.
DMRE	No. WECC dominated by institutional barriers.	Promote sectoral collaboration. Enable centralised of systems such as data management.
DEFF	No. Dissemination of information across these three critical sectors is lacking. Collaboration with other government departments, research, and industries, particularly within the emerging climate science is very poor.	Cross-sectoral workshops, bilateral agreements, coordinated social and physical data management and research approaches, increase departmental interfaces.
Energy Industry – Eskom	No. Collaboration is still sectorally approached. For example, coordination can exist from the supply perspective but is lacking in the implementation of different strategies and policies to increase efficiency. The lack of translation of theory into practice creates barriers of	Cross-sectoral coordination, ministerial and bilateral agreements on water, energy and climate change.

	coordination across the stakeholders.	
Water Industry – Rand Water	No. Key governmental stakeholders not coordinated in a manner that collectively addresses the WECC challenges.	Collaborate with water-users to promote awareness and water-saving initiatives.
Local government	No. Local government not involved in addressing WECC nexus at a national level.	Consider the localised dynamics such as water and energy requirements. Strengthen the local level interactions.
NGO	No. Communities entirely excluded from WECC related matters.	Enable community participation in critical decision-making processes. Consider community requirements. Establish government-industry-community committees that are independently managed.
Research and Academia	No. Sectoral approaches and preferences still dominate the WECC. Some departments are more coordinated than others.	Combined research activities within WECC to close the knowledge gap between local communities, industries, researchers and policy-makers.

Source: Based on field surveys (2019)

The majority of the participants are of the view that the coordination and collaboration efforts are insufficient to deal with the existing WECC challenges in South Africa. One significant example is the lack of collaboration and coordination from key governmental departments in the water, energy and climate change sectors particularly in the planning and development of policy. For instance, when asked about collaboration amongst government stakeholders, WECC-A explicitly raised concerns on the:

> "There is a *lack of collaboration amongst the policy-makers and different stakeholders such as local communities particularly in the inclusion of emerging science such as climate change in the nexus*". *- (Personal communication: focus group discussion on the 20th of September 2019).*

Responses such as the one given above raise questions about how collaboration can be enforced when it's not being practised among key ministries of WECC. In Kenya, for example, the lack of collaboration and cooperation among key levels of institutions resulted in conflicting and duplicated plans in the country's water, energy, and food supply systems (Aboelgna et al., 2018). This corroborates the views of Mathetsa et al. (2019) that there is a lack of collaboration among key sectors and organisations responsible for both operational and policy implementation. This further intensifies the sectoral mandate approach and ineffectiveness in the management of WECC. Another key challenge raised by research participants is the lack of collaboration with other sectors such as industries and communities to address WECC challenges. This is despite the communities' crucial role in providing necessary information to deal with WECC issues while at the end of the food-chain thus being highly implicated by the nexus imminence (Aboelgna, 2018; US DoE, 2014). Also, the concerns raised by the researchers and government sectors are the competition amongst research institutions which further extend the knowledge gap between researchers, government agencies and communities. This observation supports the views of Conway et al. (2015) who argued that there is an exacerbation of the knowledge gap between both researchers and non-researchers which results in exclusions during decision-making processes and, thus hindering the opportunity to identify and incorporate all levels of society in the effective management of WECC.

The findings seem to suggest that the vertical (governmental) and horizontal (all sectors) coordination and collaboration are not intensified in the country. This is worsened by institutional barriers within the WECC resulting from the complex connection between these three elements (Aboelgna et al., 2018). This pertaining situation is unlike in the water resources management which DWS (2013), Karar (2008) and Pollard and Du Toit (2008) are of the view that the establishment of institutional arrangements such as CMA has enabled the promotion of collaboration and coordination. While Aboelgna (2018) suggested that changes in the institutional structures, procedural and communication instruments are necessary for promoting coordination and collaboration, participants, on the other hand, suggested implementation of platforms such as co-planning and policy development, inter-ministerial

task teams, cross-sectoral coordination, bilateral agreements, and joint committees across the technical, research and academia, ministerial and local levels as well as enablement of financial structures where WECC components are of concern. This seems to suggest that implementation of the coordinated and collaborative strategy has the potential to trigger effective WECC management thereby enabling tools such as funding, data, information, modelling, technology, policy analysis, and political will to be implemented and to result in minimising the implications of the WECC on all sub-sectors of the economy.

4.4.3. Perceptions of the research participants on the policy development on WECC in South Africa

The policy is one of the key drivers of efficiency in resource consumption. The growing demand for communities to address the water and energy efficiencies while curbing climate change impacts suggests that robust policies are required. However, it is argued by Carpenter (2015), Head and Cammerman (2010) and US-DoE (2014) that the complexity and fragmentation of water, energy and climate change sectors require deviations in the decision-making landscape of WECC with policy integration one of the key factors warranting these changes. Driven by the interests of multi-stakeholders on WECC, this sub-section assesses the views of research participants on the insight of the current policy decision-making landscape in South Africa. The views of different participants are illustrated in Table 4.4.

Table 4.4: Perceptions of research participants on policy development in South Africa

Policy development on WECC	No. of participants	No. of responses	Percentage (%)
Policy integration	**43**		
Fully		6	14
Moderately		14	33
Poor		23	53
Consultation during policy development	**43**		
Fully		7	16
Moderately		11	26
Poor		25	58

Source: Based on field surveys (2019)

The responses were divided into two sub-themes namely the views of participants on WECC policy integration and consultations of key stakeholders during policy development. The majority of research participants (i.e. 53%) are of the view that the current policies across the water, energy and climate change sectors are not developed in integration. For instance, WECC-A said that *"despite the emergence of climate change as an overarching component in the energy and water supply, the development of the climate change water, and energy policies are still not aligned"(Personal communication: focus group discussion on the 20th of September 2019)*. The segmented policy development, which is also observed by several studies in the country (Conway et al., 2015; Mabhaudhi et al., 2016; Mathetsa et al., 2019), validates the existence of sectoral mandate within different governmental departments. This is a common challenge across different global communities (Aboelgna et al., 2018; Brasillian et al., 2011). This segregation also raises concerns during the policy implementation stages in which WECC-D_1, WECC-D_2, WECC-D_3, and WECC-C highlights conflicting compliance expectations from different policymakers. Also, responses from the participants confirm the existence of sectoral mandated policies that are limited to certain coupled interactions. For instance, WECC-B_1 pointed out that there is a development of *"key departmental policies such as Sustainable Hydropower Generation Policy which is responsible to ensure that there is sufficient water available for the hydropower generation technology" (Personal communication: focus group discussion on the 19th September 2019)*. Other research participants, however, indicated that they are not aware of such policy thus suggesting a "silo" approach in the development of these critical policies. However, several research participants (i.e. 33%) have observed an improvement with regards to the development of policies in consideration of each of the WECC elements. For instance, WECC-G and WECC-L stated that the development of the energy policy, Integrated Resource Plan 2010-2013 in consideration with water scarcity and climate change impacts is another example demonstrating the progress made by South Africa on drafting policies that drive alignment of WECC nexus elements.

One of the key drivers of segregated policy development is the lack of consultation amongst broader stakeholders in the WECC nexus (Cammerman, 2009; Head and Cammerman, 2010). The findings of this study reveal that 58% of the research participants are of the view that the current consultation approach among key WECC stakeholders is poor and unsatisfactory. This lack of consultation is, according to Chambers (1994) and GWP (2000) aggravated by the top-down decision-making approach practised in most societies. Despite the suggestions by Head and Cammerman (2010) and Mohtar (2017) that complex problems such as WECC require a

multiscale approach particularly at the policy-making level, the findings of this study suggest that the current policies in South Africa are not integrated due to lack of stakeholder consultation. This observation strongly suggests that there is a need for a revised decision-making and policy development landscape which will be based on broader stakeholder engagement with the intent to increase efficiencies to manage WECC nexus in South Africa. Until such developments are achieved, the WECC nexus will continue to hamper the socio-economic development as well as environmental wellbeing in the country. This assertion is made given the current and projected impacts associated with climate change in South Africa. Therefore, there is an urgent need for integrated policies and strategies that have a bearing on addressing the challenges with WECC.

4.4. Conclusions

The study applied PA to assess the views of numerous WECC stakeholders and the effectiveness of current tools such as policy development and collaboration to manage this nexus in South Africa. Based on the perceptions of the research participants, the study revealed three key findings. Firstly, it is evident that there are limited understanding and acknowledgement of WECC existence in South Africa. This is validated by the least number of research participants demonstrating their understanding of this coupled WECC interconnections. This limited understanding is regardless of the notable level of education and experience that the research participants have on either of the sectors. Secondly, despite the growing need to address the WECC challenges, the study observes that a lack of coordination and collaboration both vertically (decision-makers such as government departments) and horizontally (stakeholders such as government departments, industries, and local communities) scales still exists in South Africa. It is, however, noted that the need for collaboration is comprehended by different stakeholders, given the efforts to discuss and raise concerns on lack of it thereof. Thirdly, sectorally-driven policy planning and development are still dominant in South Africa. It is, however, observed that there are efforts to integrate the development of policies in recognition of the influence of each sector. Initiatives and engagement such as ministerial committees, donor-funding, and research teams have been observed to promote collaboration and integrated approach.

One of the contributions of this study is the important role that the PA plays in promoting a holistic and coordinated management of WECC in South Africa. The three data collection

techniques applied in this study revealed that this approach is pivotal in assessing WECC, thus maximising the opportunities of the country to capture the risks and opportunities that these nexus have on all sub-sectors of the economy. It is, therefore, suggested that South Africa must look into the prospects of developing the institutional and policy framework that will promote the implementation of PA within the WECC nexus systems. Part of the requirements in this process will be investments in skills development of those actors who are mandated to work within the sectors that can manage the impacts of this WECC nexus. Also, the country must establish a data management system from which all actors within the WECC system can draw information to align their policies and strategies holistically.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Overview of the key findings of the study

This research attempted to establish the potential of the Integrated Water Resource Management (IWRM) approach in the assessment of Water-Energy-Climate Change (WECC) nexus in South Africa. This assessment is done to promote an integrated and holistic approach to managing this nexus. Firstly, the developments on the global, regional and local studies were reviewed to assess the context in which this nexus was researched, particularly in South Africa. This is followed by an attempt to comprehend this nexus using two of the four principles of the IWRM framework. In the first instance, the occurrence of this nexus in South Africa is verified through the application of "water as a finite resource" principle. Secondly, the application of the "participatory approach" principle to promote collaborative and coordinated governance of this nexus based on the perceptions of key stakeholders was conducted. Given the undertaken analysis, it can be confirmed that the study attained all its objectives. This study made several important findings that drive the management of the WECC towards a holistic and integrated manner.

Firstly, the study revealed that, although there is comprehensive research work conducted on the nexus configurations such as water-energy-food and water-energy, studies around WECC are still lacking behind. The deficit is mostly experienced in the Sub-Sahara Africa (SSA) region and South Africa in particular. This is despite profound indications that the elements of water, energy and climate change are conversely linked in South Africa where a lack of balance in the management of one element influences the efficiency of the other two. This significantly influences the country's plans to attain its national developmental endeavours. One of the key observations from the literature appraisal, which includes a review of key policies from the three sectors, is that there is a prevailing "silo" approach in the planning and strategic development of key policy as well as mitigation and adaptive measures to manage implications of these three elements. These findings show the urgent need for South Africa to strengthen investigations around WECC to comprehend this nexus. One of the proposed tools to understand this nexus, the IWRM framework, is argued in this study to be suitable in

understanding this nexus. This framework is suggested due to its ability to promote holistic and integrated management of water resources and related activities such as land use, energy, and food production. Also, this proposition is encouraged by the centric role that water plays in the nexus and other sub-sectors of the economy.

The second major finding of this study advocates for the WECC nexus to be assessed and managed from the water resource management perspective in South Africa. This is driven mainly by the deteriorating status of the water quality and quantity in the country. The empirical evidence obtained from the Waterberg and Highveld regions suggests that physical data can be used to validate the occurrence of this nexus in South Africa. The findings of this research provide an understanding of how water-related data and information can be useful to investigate the inextricable linkage between water, energy and climate change. In general, the sustainable management of water is vital in addressing the WECC as it is central in energy production and influenced by climate variabilities in the country.

The third main finding highlighted the significance of the participatory approach in understanding the WECC nexus and revealing some of the challenges that make the WECC less governable. This approach is regarded as one of the most effective tools in addressing complex issues that involve multiple stakeholders. The evidence from this study suggests that, despite this nexus being understood and acknowledged by some actors, the stakeholders revealed several gaps emerging from the management of this nexus. Examples of some of these gaps include a lack of coordination and collaboration, segregated policy development, and limited consultation among key stakeholders of WECC. This study reveals that stakeholder engagement can influence the adaptation of contemporary systems that can positively influence the management of WECC. This is based on the view that, during this approach, there is data, information, and knowledge sharing among key stakeholders thus possibly driving decision-makers towards informed decision-making. Also, these findings have significant implications for the understanding of how complex systems such as WECC are interlinked and their role towards the attainment of the country's national developmental plans.

The fourth major finding highlights the importance of both physical and social data in the management of WECC. It was revealed during the study that existing deficits related to data management, particularly accessibility and reliability, from some sectors is one of the challenging factors impeding the effective management of this nexus. This results in deficits

such as uninformed decision-making particularly in the development of policies and strategies aimed at managing these elements.

In conclusion, the above-mentioned findings highlight the need for a holistic view of promoting effective management of WECC. This is to ensure resilient and adaptive measures towards climate change, thus enabling processes to improve both water and energy security in the country, which are linked to the attainment of the SDGs. Also, this study strengthens the idea that the understanding and promotion of coordinated and integrated management of this nexus can be achieved through the application of the IWRM. This can mitigate the risks emanating from this nexus particularly those linked to sustainable development goals.

5.2. Key recommendations

For South Africa to attain her sustainable developmental goals the inextricable complex interaction between the water, energy and climate change should not be ignored. Therefore the following pointers can be taken into consideration to enhance the understanding and effective management of the WECC nexus:

i. Improve the management of water resources

Water plays a key role in sustaining all the sub-sectors of the economy in South Africa. As such, there is an urgent need to enforce the sustainable management of this resource in the country. It is suggested that improvements and enforcements of management instruments such as monitoring and reporting be emphasised. The Department of Water and Sanitation, in consultation with key stakeholders such as those in the agriculture, energy, local government, and water user associations should lead the strengthening of water resource management at catchment level. This can be done through initiatives such as integrated regional/catchment studies, joint water treatment, and water reuse projects, integrated monitoring and reporting.

ii. Participation of stakeholders

Stakeholder participation in the management of WECC is an absolute imperative. The stakeholder engagement in WECC should be widened to ensure that all actors particularly the marginalised and those at the bottom of the value chain forms part of the decision-making process. Their reasonable suggestions should be considered during policy development.

Engagements activities such as stakeholder dialogue should be encouraged to ease the identification of risks and opportunities emanating from this nexus. It is suggested that a WECC Committee, governed by the presidency or nominated department, be established in different regions or catchment where this nexus is of concern. The terms of references of the committee shall be gazetted and include all stakeholders across different sectors in each region.

iii. Monitoring and reporting

The current system of monitoring and reporting on water, energy and climate change is not sufficient to address WECC challenges. For example, monitoring and reporting of key WECC indicators such as greenhouse gases and energy consumption are only limited to big industries. It is recommended that systems be put in place to ensure that the WECC indicators across all levels of the value chain are captured and used decision-making processes. Also, modelling such as those of water, energy and climate change prediction should form part of the planning processes of these elements.

iv. Data management, integration, and accessibility

The WECC data from all key sectors should be managed in an integrated manner. It is recommended that a central system that can be able to incorporate these data sets be established and implemented across all key role players such as government departments and industry. Also, there should be avenues to ensure the data is accessible to ensure transparency.

v. Collaboration and coordination

Collaborated and coordinated interactions among key WECC stakeholders should be improved as the current ones are ineffective. These collaborations should be established at all levels of governance such as ministerial departmental, local government or industries. Establishment of strategies such as institutional frameworks is key in improving these collaborations. This is likely to promote integration in planning, policy development, and implementation; and close the gaps between these three sectors.

vi. Policy integration

The policies on the elements of WECC should be aligned with each other and developed in an integrated manner to drive resource efficiency and environmental wellbeing in the country. The

current approach, which isolates policies between the sectors of water, energy and climate change, is ineffective in managing WECC nexus It is, therefore, recommended that an advisory panel or intergovernmental working group on WECC which should look to establish this policy integration be established and implemented.

5.3. Recommendations for future research

In light of the above conclusions and recommendations, the study highlights the prospects of investigating contemporary solutions to South Africa's WECC challenges. It is recommended that these include systems for acquiring, centralised storage, validation, and accessibility of physical data to enable informed decision-making by key stakeholders. This should further promote the studies that incorporate or utilises this data into modelling and policy development associated with water, energy and climate change elements. Furthermore, the study recommends the investigation of possible ways of promoting a participatory approach within WECC management. It recommended that further studies should seek to develop strategies to ensure that tools such as stakeholder engagement are effectively used in understanding and capturing the opportunities of this nexus.

REFERENCES

Aboelga, H.T., Khalifa, M., Mcnamara, I., Ribbe, L. and Sycz, J. 2018. The Water-Energy-Food Security Nexus, A review of Nexus literature and ongoing Nexus initiatives for policymakers. Nexus Regional Dialogue Programme (NRDP). Bonn, Germany. https://doi.org/10.1016/j.wen.2018.08.002.

Ackom, E. 2014. Energy, water and climate nexus: A case study of Cameroon. *In Nexus 2014: Water, food, and energy.* Online:http://orbit.dtu.dk/files/128129576/nexus_2014_abstract_book.pdf (Accessed: 14 March 2018). https://doi.org/10.1115/imece2014-36502.

Alam, A. and Ihsan, S. 2012. Role of Participatory Rural Appraisal in Community Development (A Case Study of Barani Area Development Project in Agriculture, Live Stock and Forestry Development in Kohat). *International Journal of Academic Research in Business and Social Sciences* 2(8).

Al-Saidi, M. 2017. Conflicts and security in integrated water resource management. *EnvironmentalScience and Policy* 73, 38-44. https://doi.org/10.1016/j.envsci.2017.03.015.

Barreteau, O., Bots, P., Daniell, K., Etienne, M., Perez, P. Barnaud, C., Bazile, D., Becu, N., Castella, J.C., Dare, W. and Trebuil, G. 2013. Participatory approaches. *In: Simulating Social Complexity, Chapter 10. Springer. Manchester.* United Kingdom.

Barbosa, M.C., Mushtaq, S. and Alam, K. 2017. Integrated water resources management: Are river basin committees in Brazil enabling effective stakeholder interaction?. *Environmental Science and Policy, 76(C), 1-11.*

Bindra, S.P., Hamid, A., Salem, H., Hamuda, K. and Abulifa, S. 2013. Sustainable integrated water resources management for energy production and food security in Libya. *Procedia Technology,* 12, 747–752. https://doi.org/10.1016/j.protcy.2013.12.558.

Biswas, A.K. 2004. Integrated water resources management: A reassessment. *International Water Resources Association* 29(2): 248-256. https://doi.org/10.1080/02508060408691775.

Biswas A.K. 2008. Integrated Water Resources Management: Is it working? *International Journal of Water Resource Development*, 24, (1), 5-22.

Bizikova, L., Roy, D., Swanson, D., Venema, H.D., and MCcandless, M. 2013. The Water-Energy-Food Security Nexus: Towards a practical planning and decision-support framework for landscape investment and risk management. *International Institute of Sustainable Development Report*. Online:http://www.cilt.uct.ac.za/sites/default/files/image_tool/images/91/Bizikova%20et%20al.%20wef_nexus_2013%20IISD.pdf. (Accessed: 22 February 2019).

Bizikova, L., Roy, D., Venema, D.H., MCcandless, M., Darren, Swanson, Khachtryan, A., Borden, C., and Zubrycki, K. 2014. The Water-Energy-Food Nexus and Agricultural Investment: A sustainable development guidebook. *International Institute for Sustainable Development (IISD).*

Bless, C., Higson-Smith, C. and Sithole S.L. 2013. Fundamentals of social research methods: an African perspective. 5th edition. *Juta & Co*. South Africa.

Brazilian, M., Rogner, H., Howells, M., Hermann, S., Douglas, A., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, S.J.R. and Yumkella, K.K. 2011. Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy,* 39, 7896-7906. https://doi.org/10.1016/j.enpol.2011.09.039.

Bryman, A. 2012. The debate about quantitative and qualitative research: A question of method or epistemology? Blackwell Publishing.

Burt, J.C., Du-Toit, D.R., & Neves, D. 2005. Learning about participation in IWRM: A South African Review. *Water Research Commission*, Pretoria, South Africa.

Cammerman, N .2009. Integrated water resource management and the water, energy, climate change nexus: a discussion report. Masters Thesis, University of Queensland, Australia.

Carpenter, A.M. 2015. Water availability and policies for the coal power sector. IEA Clean Coal Centre. Report no ccc/256. United Kingdom.

Carr, W. 2006. Philosophy, Methodology and Action Research. *Journal of Philosophy of Education*, 40 (4), 421-435.

Carter, S. and Gulati, M. 2014. Climate change, the Food Energy Water Nexus and food security in South Africa: Understanding the Food-Energy-Water Nexus. *WWF-SA, 1-17.* https://doi.org/10.1115/imece2014-36502.

Chambers, R. 1994. Participatory rural appraisal (PRA): Analysis of experience. *World Development,1253-1268.*

Charmaz, K. 2013. *Constructive grounded theory: A practical guide through qualitative analysis.* SAGE Publications, London.

Cheru, F. (2002). *African Renaissance: Roadmap to the challenge of globarisation*. ZED Books, London.

Chilundo, M., Kelderman, P. and O'Keeffe, J. H. 2008. Design of a water quality monitoring network for the Limpopo River Basin in Mozambique. *Physics and Chemistry of the Earth* 33: 655-665.https://doi.org/10.1016/j.pce.2008.06.055.

Claasen, M. 2013. Integrated water resource management in South Africa. *International Journal of Water Governance,* 1, 323-338.

Conway, D., Van Garderen, E. A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Osborn, T., Ringler, C., Thurlow, J., Zhu, T. and Dalin, C. 2015. Climate and Southern Africa's water–energy–food nexus. *Nature Climate Change* 5(9), 837-846. https://doi.org/10.1038/nclimate2735.

Copeland, C. and Carter, N. T. 2017. Energy-water nexus: The water sector's energy use. Congressional Research Service Report prepared for members and committees of congress, 24 January 2017.

Cullis, J.D.S., Walker, N.J., Ahjum, F. and Rodrigues D.J. 2018. Modelling the water-energy nexus: should variability in water supply impact on decision making for future energy supply options? *International Association of Hydrological Sciences, 3*76, 3-8.

Dabrowsky, J.D. and De-Klerk, L.P .2013. An assessment of the impact of different land use activities on water quality in the upper Olifants River catchment. *Water SA, 39(2)* 231-244. https://doi.org/10.4314/wsa.v39i2.6.

Dai, J., Wu, S., Han, G., Weinberg, J., Xie, X., Wu, X., Song, X., Jia, B., Xue, W., Yang, Q. 2018. Water-energy nexus: A review of methods and tools for macro-assessment. *Appl. Energy*, 210, 393–408. DOI:10.1016/j.apenergy.2017.08.243.

Dawson, C. 2002. Practical Research Methods, user-friendly guide to mastering research techniques and projects. *How-to books*. The United Kingdom.

Denby, K., Movik, S., Mehta, L. and Van Koppen, B. 2016. The 'trickle down' of IWRM: A case study of local-level realities in the Inkomati Water Management Area, South Africa. *Water Alternatives*, 9(3), 473-492.

DeNicola, E., Aburizaiza, S. O., Siddique, A., Khwaja, H., and Carpenter, D.O. 2015. Climate Change and Water Scarcity*: The Case of Saudi Arabia. Annals of Global Health 81(3), 342-353.* DoI: https://doi.org/10.1016/j.aogh.2015.08.005.

Dennis, I. and Dennis, R. 2012. Climate change vulnerability index for South African aquifers. *Water SA* 38(3), 417- 426. DOI: https://doi.org/10.4314/wsa.v38i3.7.

Denscombe, M. 2003. The Good Research Guide for small-scale social research projects. Second Edition. *Open University Press*. USA.

Department of Energy (DoE). 2013. Integrated Resource Plan for electricity: 2010-2030 Revision 2. DoE, Pretoria, South Africa. Online: http://www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (Accessed: 20 February 2018).

DoE. 2018. Integrated Resource Plan. 2018. Online:http://www.energy.gov.za/IRP/irp-update-draft-report2018/IRP-Update-2018-Draft-for-Comments.pdf. (Accessed: 26 March 2019).

Department of Environmental Affairs (DEA). 2015. South Africa's greenhouse gas inventory report 2000-2015. Online:

https://www.environment.gov.za/sites/default/files/reports/GHG-National-Inventory-Report-SouthAfrica-2000-2015.pdf. (Accessed: 26 July 2019).

DEA .2015a. National Climate Change Response. White Paper. Pretoria, South Africa.

DEA. 2015b. South Africa's 1st Annual Climate Change Report: A Synopsis of South Africa's 2015 Annual Report on Monitoring Climate Change Responses, Theme A. Pretoria, South Africa.

DEA. 1998. National Environmental Management Act, 107 of 1998. The Republic of South Africa.

Department of Water and Sanitation (DWS). 2004. National Water Resource Strategy (NWRS): Water for equitable and sustainable future. Government printers. Pretoria, South Africa.

DWS. 2013. National Water Resource Strategy (NWRS): Water for equitable and sustainable future. Government printers. Pretoria, South Africa.

Dungumaro, E.W. and Madulu, N. F. 2003. Public participation in integrated water resource management: *the case of Tanzania. Physics and Chemistry of the Earth*, 28. 1009-1014.

Electricity Power Research Institute. 2010. Sustainable water resource management: Case study on new water paradigms, 3.Online: http://www.ndwrcdp.org/documents/DEC6SG06a/Case%20Studies%20on%20New%20Water%20Paradigm.pdf. (Accessed: 20 April 2018).

Endo, A., Burnett, K., Orencio, P.M., Kumazawa, T., Wada, C.A., Ishii, A., Tsurita, I., Taniguchi, M., 2015. Methods of the water-energy-food nexus. *Water (Switzerland)*, 7, 5806–5830. DOI:10.3390/w7105806.

Emalahleni Local Municipality .2019. Integrated Development Plan 2018-2019 [online: https://www.emalahleni.gov.za/online2/index.php/documents/file/1348-2018-19-final-idp. Accessed: 10 November 2019.

Energy and Water Integration Act. 2009. S 539 of The Bill: The senate of the United States, 111th congress 1st session. The United States, 5 March 2009.

European Corporation for Science and Technology (COST). 2009. The energy-water nexus: Managing the links between energy and water for a sustainable future. COST explanatory workshop, Brussels, 19-21 January 2009.

Eskom. 2012. Water, Energy and Development. Sustainability Group, Research, Testing and Development. Johannesburg, South Africa. pp 6.

Eskom.2019.Online:http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/Pages/Electricity_Generation.aspx. (Accessed: 26 March 2019).

Eskom. 2016. Eskom water management policy. Document identifier: 32-1163. Online: https://hyperwave.eskom.co.za/Eskom/Group%20Capital/Eskom%20Real%20Estate/SHEQ/Environmental%20Management%20System_ISO%2014001/North%20West%20%26%20Free%20State/Free%20State/Bloemfontein/4.4.6.%20Operational%20Controls/Water%20Management/Policy.pdf (Accessed: 18 June 2018).

ESKOM .2019b. Online: https://www.eskom.co.za/OurCompany/SustainableDevelopment/Pages/CDM_Calculations.aspx. (Accessed: 11 March 2019).

European Cooperation in Science and Technology [COST] .2009. The energy-water nexus: Managing the links between energy and water for a sustainable future. *COST Explanatory Workshop*. Brussels, 19-21 January 2009.

Fatch, J.J. 2009. Local participation in transboundary water resources management: The case of Limpopo Basin, Zimbabwe. MSc Thesis. University of Zimbabwe.

Flammini, A., Puri, M., Pluschke, L., Dubois, O, 2014. Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative; Climate, Energy and Tenure Division (NRC), Food and Agriculture Organization of the United Nations (FAO): Rome, Italy.http://www.fao.org/3/a-i3959e.pdf.

Fulazzaky, M.A. 2014. Challenges of Integrated Water Resources Management in Indonesia. *Water,* 6**,** 2000-2020.https://doi.org/10.3390/w6072000.

Funke, N., Oelofse, S.S.H., Hattings, H., Ashton, P.J. and Turton, A.R. 2007. IWRM in developing countries: *Lessons from the Mhlatuze catchment in South Africa*. *Physics and Chemistry of the Earth,* 32, 1237-1245. https://doi.org/10.1016/j.pce.2007.07.018

Germs, W., Coetzee, M.S., Van Rensburg, L. and Maboeta, M.S. 2004. A preliminary assessment of the chemical and microbial water quality of the Chunies River–Limpopo. *Water SA*, 30(2), 267-272.

Gobin, A., Sparks, D., Okedi, J., Armitage, N. and Ahjum, F. 2019. Assessing the energy and carbon footprints of exploiting and treating brackish groundwater in Cape Town. *Water SA,* 45 (1), 63 – 74. https://doi.org/10.4314/wsa.v45i1.08.

Goldstein, N. C., Newmark, R. L., Whitehead, D. C., Burton, E., McMahon, J. E., Ghatikar, G. and May, D.W. 2008. The energy-water nexus and information exchange: Challenges and opportunities. *International Journal of Water*, *4*(1\2), 5-24. https://doi.org/10.1504/ijw.2008.018144.

Global Donor Platform for Rural Development.2017.Online: https://www.donorplatform.org/news-agenda-2030/exploring-the-power-of-nexus-thinking-in-sdgs-implementation.html. (Accessed: 01 March 2019).

Global Water Partnership. 2000. Integrated water resources management: *Report by Technical Advisory Committee*. TAC background papers no. 4, Stockholm, Sweden.

Online:https://www.gwp.org/globalassets/global/toolbox/publications/background-papers/04-integrated-water-resources-management-2000-english.pdf (Accessed: 26 June 2017).

Gobin, A., Sparks, D., Okedi, J., Armitage, N. and Ahjum, F. 2019. Assessing the energy and carbon footprints of exploiting and treating brackish groundwater in Cape Town. *Water SA*, 45 (1), 63 – 74.

Head, B. and Cammerman, N. 2010. The water-energy nexus, a challenge for knowledge and policy. Urban Water Security Research Alliance, Technical report No. 39. Online: http://www.urbanwateralliance.org.au/publications/UWSRA-tr39.pdf (Accessed: 28 March 2018).

Hejazi, M.I., Edmonds, J., Clarke, L., Kyle, P., Davies, E., Chaturvedi, V., Wise, M., Patel, P., Eom, J. and Calvin, K. 2014. Integrated assessment of global water scarcity over 21st century under multiple climate change mitigation policies. *Hydrology and Earth Systems Science*, 18 (8), 2859-2883. https://doi.org/10.5194/hess-18-2859-2014.

Heldt, S., Rodriquez-de-Francisco, J. C., Dombrowsky, I., Feld, C. K. and Karthe, D. 2017. Is the EU WFD suitable to support IWRM planning in non-European countries?: Lessons learnt from the introduction of IWRM and river basin management in Mongolia. *Environmental Science and Policy*, 75:28-37. https://doi.org/10.1016/j.envsci.2017.05.009.

Hoolohan., C., A. Larkin, C. McLachlan, R. Falconer, I. Soutar, J. Suckling, L. Varga, I. Haltas, A. Druckman, D. Lumbroso, M. Scott, D. Gilmour, R. Ledbetter, S. McGrane, C. Mitchell, D. Yu. 2018. Engaging stakeholders in research to address water–energy–food (WEF) nexus challenges. *Sustainability Science (2018)*, 13, 1415–1426.

Hussey, K. and Pittock, J. 2012. The Energy-Water Nexus: Managing the Links between Energy and Water for Sustainable Future. *Ecology and Society*, 17 (1), 31-39. https://doi.org/10.5751/es-04641-170131.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the IPCC by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976. https://doi.org/10.2134/jeq2008.0015br.

IPCC. 2014. Climate Change 2014. Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O.R., Pichs-Madruga, Y., Sokona, E., Farahani, S., Kadner, K., Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. Von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://doi.org/10.1017/cbo9781139151153.002.

International Energy Agency (IEA). 2016. Energy, climate change and environment: A report by IEA. Online:

http://www.iea.org/publications/freepublications/publication/ECCE2016.pdf (Accessed: 23 May 2017). https://doi.org/10.1787/9789264239272-en.

Jagerskog, A., Clausen, T. J., Holmgren, T. and Lexen, K. 2014. Energy and Water: The vital link for a sustainable future: Report for the world water week. Report no 33. Stockholm, Sweden, 31st August– 5th September 2014.

Jingling, L., Yun, L., Liya, S., Zhiguo, A. and Baoqiang, Z. 2010. Public participation in water resources management of Haihe river basin, China: the analysis and evaluation of status quo. *Procedia Environmental Sciences*, 2, 1750–1758.

Karar, E. 2008. Integrated water resource management (IWRM): Lessons from implementation in developing countries: Foreword to the IWRM conference special edition. *Water SA, 34(6),* 661-664. https://doi.org/10.4314/wsa.v34i6.183666.

Kawulich, B. (2005). Participant Observation as a Data Collection Method [81 paragraphs]. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 6(2), Art. 43, http://nbn-resolving.de/urn:nbn:de:0114-fqs0502430. Online: http://www.qualitative-research.net/index.php/fqs/article/view/466/996. (Accessed: 08th October 2019).

Kirchherr J, and Charles K (2018) Enhancing the sample diversity of snowball samples: Recommendations from a research project on anti-dam movements in Southeast Asia. *PLoS ONE*, 13(8). e0201710. https://doi.org/10.1371/journal.pone.0201710.

Kothari, C.R. (2004). Research Methodology: Methods and Techniques. Second revised Edition. *New Age International Publishers*. New Delhi.

Kubanza N.S and Simatele M.D. (2019). Solid waste management and environmental injustice in poor communities in Kinshasa: A cultural theory and systems approach. *Journal of Environmental Management and Sustainable Development*, 8, 1, ISSN 2164-7682.

Kubiszewski, I. and Cleveland, C. 2012. United Nations Conference on Environment and Development, Rio de Janeiro, Brazil. Online: http://editors.eol.org/eoearth/wiki/United_Nations_Conference_on_Environment_and_Developmnt_(UNCED),_Rio_de_Janeiro,_Brazil (Accessed: 26 March 2018). https://doi.org/10.1007/springerreference_29770.

Leendertse, K., Mitchell, S.A.M. and Harlin, J. 2008. IWRM and the environment: A view on their interaction and examples where IWRM led to better environmental management in developing countries. *Water SA*, 34(6): 691-698. https://doi.org/10.4314/wsa.v34i6.183671

Legislative Sector South Africa. 2013. Public Participation Framework for the South African Legislative Sector. [Available online: http://sals.gov.za/docs/pubs/ppf.pdf, (accessed: 18 November 2019).

Lephalale Local Municipality (2019). Integrated Development Plan 2017_2018. [Available Online:http://www.lephalale.gov.za/docs/SDBIP/Draft%20IDP%202017-18%20Lephalale%20Municipality.pdf. (Accessed: 10 November 2019).

Liu, J., Yang, H., Cudennec, C., Gain, A.K., Hoff, H., Lawford, R., Qi J., De Strasser, L., Yillia, P.T. and Zheng, C .2017. Challenges in operationalizing the water–energy–food nexus. *Hydrological Sciences Journal*, 62 (11), 1714–1720. https://doi.org/10.1080/02626667.2017.1353695.

Mabhaudhi, T., Mpandeli, S., Madhlopa, A., Modi, A.T., Backeberg, G. and Nhamo, L. 2016. Southern Africa's Water-Energy Nexus: Towards Regional Integration and Development. *Water*, 8, *(6): 1-21*. https://doi.org/10.3390/w8060235.

Madhlopa, A., Pegram, G., Sauka, S., Sparks, D., Keen, S. and Moorlach, M. 2016. The water-energy nexus in the context of climate change: Investigating trade-offs between water use efficiency and renewable energy options for South Africa. Report to the Water Research Commission. WRC Report No 2239/1/15. March 2016. https://doi.org/10.1016/j.rser.2015.03.051.

Manzungu, E. 2004. Water For All: Improving Water Resource Governance in Southern Africa. gatekeeper series no.113. International Institute for Environment and Development Natural Resources Group and Sustainable Agriculture and Rural Livelihoods Programme. Online:https://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/6097/113.pdf?sequence=1&is Allowed=y. (Accessed: 22 October 2019).

Masters, L. 2009. Climate change, energy and South Africa's foreign policy: The road to Copenhagen. *South African Institute of International Affairs*, Occasional Paper No. 47.

Mathekga, R. and Buccus, I. 2006. The challenge of local government structures in South Africa: *securing community participation*. Critical Dialogue Public Participation Rev. 2 (1),11-17.
Online:http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.626.6280&rep=rep1&type=pdf. (Accessed: 06th September 2019).

Mathetsa, S.M., Simatele, M.D., Rampedi I.T. and Gericke, G. 2019. Perspectives on integrated water resource management and its relevance in understanding the water-energy-climate change nexus in South Africa. *Journal of Energy in Southern Africa*, 30 (3), 11-21.

Mathetsa, S.M. 2016. Assessing water quality status by means of the Driver-Pressure-State-Impact-Response (DPSIR) model around Mapungubwe National Park, Limpopo Province, South Africa. MSc Thesis. University of South Africa, South Africa.

Mills, J., Bonner, A. and Francis, K. 2006. The development of constructivist grounded theory. *International Journal of Qualitative Methods*, 5(1), Article 3. Online: http://www.ualberta.ca/~iiqm/backissues/5_1/pdf/mills.pdf. (Accessed: 14 October 2019).

Mukheibir P. and Sparks D. 2003. Water resource management and climate change in South Africa: Vision, driving factors and sustainable development indicators. Report for Phase 1 of the Sustainable Development and Climate Change Project. *Energy & Development Research Centre*. University of Cape Town.

Mukheibir, P. 2008. Water Resources Management Strategies for adaptation to climate-induced impacts in South Africa. *Water Resources Management*, 22, 1259–1276. https://doi.org/10.1007/s11269-007-9224-6.

Muller, M. 2015. The 'nexus' as a step back towards a more coherent water resource management paradigm. *Water Alternatives*, 8(1), 675-694.

National Planning Commission. 2012. National Developmental Plan-2030: Our future –make it work. Online: https://www.gov.za/sites/default/files/gcis_document/201409/ndp-2030-our-future-make-it-workr.pdf. (Accessed: 22 October 2019).

Natural Resource Defense Council. 2010. Climate Change and Water Resource Management, Adaptation Strategies for Protecting People and the Environment. Online: https://www.nrdc.org/sites/default/files/waterandclimate.pdf. (Accessed: 05 May 2017).

Nesheim, I., McNeill, D., Joy, K. S., Manasi, S., Nhung, D. T. K., Portela, M. M. and Paranjape, S. 2010. The challenges and status of IWRM in four river basins in Europe and Asia. *Irrigation and Drainage Systems*, 24(3-4), 205-221. https://doi.org/10.1007/s10795-010-9103-9.

Nhamo, L., Ndlela, B., Nhemachena, C., Mabhaudhi, T., Mpandeli, S. and Matchaya, G. 2018. The water-energy-food nexus: Climate risks and opportunities in Southern Africa. *Water*, 10 (5), 567-584. https://doi.org/10.3390/w10050567.

Nkhonjera, K.G. 2017. Understanding the impact of climate change on the dwindling water resources of South Africa, focusing mainly on Olifants River basin: A review. *Environmental Science & Policy*, 71, 19–29. https://doi.org/10.1016/j.envsci.2017.02.004.

Nyathi, L. 2008. Public Participation: What has the Constitutional Court given the public. *African Journals Online*, 12 (2), 102-110.

Omer, M. A. 2008. Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews*, 12, 2265-2300. https://doi.org/10.1016/j.rser.2007.05.001.

Pahl-Wostl, C., Bhaduri, A. and Bruns, A. 2018. The nexus of water, energy and food-an environmental governance perspective. *Environmental Science and Policy*. https://doi.org/10.1016/j.envsci.2018.06.021.

Pather, V. 2010. *Eskom and Water*. In Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference. 2-6 May 2004.

Pittock, J., Hussey, K. and Dovers, S. 2015. Climate, Energy and Water: *Managing trade off's, seizing opportunities*. *Cambridge University Press*. USA.

Platonova, I. and Leone, L. 2012. The energy-water nexus in the context of climate change in developing countries: Experiences from Latin America, East and Southern Africa. *In: Synthesis Report for Climate Change and Water Program, Ottawa, Canada*. 7 November 2012.

Pollard, S. and Du Toit, D. 2008. Integrated water resource management in complex systems: How the catchment management strategies seek to achieve sustainability and equity in water resources in South Africa. *Water SA*, 34 (6), 671-680. https://doi.org/10.4314/wsa.v34i6.183668.

Prasad, G., Boulle, M., Boyd, A., Rahlao, S., Wlokas, H. and Yaholnitsky. I. 2012. Energy, water and climate change in Southern Africa. What are the issues that need further investment and research? Energy Research Centre, University of Cape Town, Cape Town, South Africa. https://doi.org/10.17159/sajs.2016/20160202.

Prasad, G., Stone, A., Hughes, A., and Steward, T. 2012. Towards the development of an Energy-Water-Food Security nexus based modelling framework as a policy and planning tool for South Africa. Paper presented at "Towards Carnegie III", a conference held at the University of Cape Town from 3 to 7 September 2012.

Prinsloo, M. 2008. Community-based participatory research: A case study from South Africa. Online:http://www.in-fusion.co.za/resources/article_community_based_research.pdf. (Accessed. 04th October 2019).

Rahaman, M.M., Varis, O., and Kajander, T. 2004. EU Water Framework Directive vs. Integrated Water Resource Management: The Seven Mismatches. *Water Resource Development*, 2 (4), 565-575.

Rasul, G. and Sharma, B. 2016. The nexus approach to water-energy-food security: an option for adaptation to climate change. *Climate Policy*, 16 (6), 682-702. https://doi.org/10.1080/14693062.2015.1029865.

Reynolds, J. and Cranston, G. 2014. Nexus thinking: Can it slow the great acceleration? Economic and Social Research Council. Online: https://www.cisl.cam.ac.uk/resources/latest-publications/nexus-thinking-can-it-slow-the-great-acceleration. (Accessed: 11 March 2019).

Salkind N.J. 2011. Exploring research. Eighth edition. Pearson Inc., Kansas. USA.

Scott A.C., Pierce A.S., Pasqualetti J.M., Jones L.A., Montz B.E., and Hoover H.J. 2011. Policy and institutional dimensions of the water-energy nexus. *Energy Policy*,39, 6622-6630.

Seymore, R., Inglesi-Lotz, R. and Blignau, J. 2014. A greenhouse gas emissions inventory for South Africa: A comparative analysis. *Renewable and Sustainable Energy Reviews*, 34, 371-379. https://doi.org/10.1016/j.rser.2014.03.028.

Siddiqi, A. and Anadon, D.L. 2011. The water-energy nexus in Middle East and North Africa. *Energy Policy*, *39*, 4529-4540. https://doi.org/10.1016/j.enpol.2011.04.023.

Simpson, G.B. and Jewitt, G.P.W. 2019. The development of the water-energy-food nexus as a framework for achieving resource security: A review. *Frontiers of Environmental Science. 7,8.* https://doi.org/10.3389/fenvs.2019.00008.

Singleton, T.C. 2010. The decision to install Flue Gas Desulphurisation on Medupi Power Station: Identification of environmental criteria contributing to the decision making process. MSc Dissertation. University of the Witwatersrand, South Africa.

Sparks, D., Madhlopa, A., Keen, S., Moorlach, M., Dane, A., Krog, P. and Dlamini, T. 2014. Renewable energy choices and their water requirements in South Africa. *Journal of Energy in Southern Africa,* 25 (4), 80-92.https://doi.org/10.17159/2413-3051/2014/v25i4a2241.

Stein, C., Pahl-wostl, C. and Barron, J. 2018. Towards a relational understanding of the water-energy-food nexus: analysis of embeddedness and governance in the Upper Blue Nile region of Ethiopia. *Environmental Science and Policy*. https://doi.org/10.1016/j.envsci.2018.01.018.

Steve Tshwete Local Municipality (2019). Integrated Development Plan 2019/20. Online: https://www.stevetshwetelm.gov.za/documents/IDP/201920/Final%20IDP%202019-2020.pdf. (Accessed:10 November 2019).

Taylor-Wood, E. and Fuller, D. 2017. 'Nexus thinking' for a secure and sustainable future. Online: http://www.entura.com.au/nexus-thinking-secure-sustainable-future. (Accessed: 01 March 2019).

The Constitution of the Republic of South Africa. 1995. South Africa.

Thomas, D.R. 2006. A General Inductive Approach for Analyzing Qualitative Evaluation Data. *American Journal of Evaluation,* 27 (2), 237-246. DOI: 10.1177/1098214005283748.

Tongco, M.D.C. 2007. Purposive sampling as a tool for informant selection. *A journal of plant, people and planet research*, 147-158.

Trollip, H. and Boulle, M. 2017. Challenges associated with implementing climate change mitigation policy in South Africa. Energy Research Centre, University of Cape Town, Cape Town, South Africa. https://doi.org/10.15641/ghi.v2i1.728.

United Nations World Commission on Environment and Development [UN WCED]. 1987. Our Common Future: Report of the World Commission on Environment and Development, Document No. A/42/427. *United Nations Publications,* New York, USA.

United Nations. 1972. Report of the United Nations conference on the human environment. Stockholm, 5-16 June 1972, Document No. A/CONF.48/14/Rev.1. United Nations Publications, New York, USA. https://doi.org/10.18356/7f7f8caf-en.

UN. 1992. United Nations Framework Convention on Climate Change. Report No. FCCC/INFORMAL/84.Online:http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf. (Date accessed: 15 March 2017).

UN. 2002. Report of the World Summit on Sustainable Development. Johannesburg, South Africa, 26 August-4 September 2002, Report no. A/CONF.199/20. *United Nations Publications*. New York, USA.

UN Climate Change Conference [UNCCC]. 2006. Africa is particularly vulnerable to the expected impacts of global warming. Paper presented at UN climate change conference in Nairobi, 2006.

United Nations. 2015. Sustainable Development Goals Post-2015: Transforming our world-the 2030 agenda for sustainable development. In: Resolution adopted by the General Assembly on 25 September 2015. Online. https://sustainabledevelopment.un.org/focussdgs.html (Accessed: 28 March 2018).

United States Department of Energy (US DoE). 2014. The water-energy nexus: Challenges and opportunities. Report for the US DoE, June 2014.

Wakeford, J.J. 2017. The water–energy–food nexus in a climate-vulnerable, frontier economy: The case of Kenya. Report Prepared for the United Kingdom department for international development by the Sustainability Institute, South Africa, March 2017.

Walmsley, J., Carden, M., Revenga, C., Sagona, F. and Smith, M. 2001. Indicators of sustainable development for catchment management in South Africa - Review of indicators from around the world. *WaterSA*, *27,* 539-550. https://doi.org/10.4314/wsa.v27i4.4968.

Water, Energy, and Climate Change [$WECC_a$]. 2015. Energy-Water-Climate Change Scenario Report. Final – approved by Scenario Planning Steering Group on 05-05-2015.

Water Research Commission (WRC) .2009. Knowledge: The cornerstone of SA's adaptation to climate change. *Water Wheel*. January\February 2009, 22-24.

WRC. 2015. How much water will we need to keep the lights on? *Water Wheel*. May/June 2015, 22-24.

WRC. 2017. Promoting sustainable economic development in water-constrained catchment. *Water Wheel*. March/April 2017, 26-28.

Wicaksono, A., Jeong, G., Kang, D. 2017. Water, energy, and food nexus: review of global implementation and simulation model development. *Water Policy,* 19, 440–462. doi:10.2166/wp.2017.214.

Winkler, H., Davidson, O., Kenny, A., Prasad, G., Sparks, D., Howells, M. and Alfstad, T. 2006. Energy policies for sustainable development in South Africa, options for the future. Energy Research Centre, University of Cape Town, Cape Town. https://doi.org/10.15641/ghi.v2i1.728.

World Bank .2017. Modeling the Water-Energy Nexus: How Do Water Constraints Affect Energy Planning in South Africa?. World Bank, Washington DC. (Online: http://documents.worldbank.org/curated/en/873091468155720710/pdf/851260BRI0Live00Box382147B00PUBLIC0.pdf. (Accessed: 06 December 2018). https://doi.org/10.1596/26255.

Yillia, P. 2019. Personal communication, 15th May 2019. Dr. Paul Yillia, International Institute for Applied Systems Analysis, Laxenburg, Lower Austria, Austria.

Yin K.R. 2014. Case Study Research, Design and Methods. Fifth Edition. *Sage Publications.* USA.

Ziervogel, G., New, M., Van Gardener, E. A., Midgley, G., Taylor, A., Hamann, R., Stuart-Hill, S., Myers, J. and Warburton, M. 2014. Climate change impacts and adaptation in South Africa. *WIREs Climate Change*,5, 605- 620.https://doi.org/10.1002/wcc.295.

APPENDIX

A. ETHICS CLEARANCE CERTIFICATE

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Mathetsa

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H17/11/31**
PROJECT TITLE	Water-energy, and climate change nexus in South Africa: Application of the integrated water resources management (IWRM) approach for sustainable development
INVESTIGATOR(S)	Mr S Mathetsa
SCHOOL/DEPARTMENT	Geography, Archaeology and Environmental Science/
DATE CONSIDERED	17 November 2017
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	13 December 2020

DATE 14 December 2017 **CHAIRPERSON** J Knight
(Professor J Knight)

cc: Supervisor : Professor D Simatele

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature

14 / 12 / 2017
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

B. PARTICIPANTS INFORMATION SHEET (INTERVIEW)

School of Geography, Archaeology and Environmental Studies
GEOGRAPHY
ARCHAEOLOGY

Participant Information Sheet (Interview)

Good Day

You are herewith invited to participate in an academic research conducted by Steven Matome Mathetsa (Student Number: 1726197), a Doctor of Philosophy (PhD) student at the University of the Witwatersrand's School of Geography, Archaeology, and Environmental Studies.

The study research is titled ***Water-Energy-Climate Change nexus in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for sustainable development***. Using Waterberg and Highveld regions for case study, the research aims at applying the IWRM tool in order to understand and improve the management of water resources within the context of an existing water and energy situations in a predicted climate change within the country.

Your selection to participate is based on your role as a professional\expert\researcher\Non-Governmental-Organization\land user\community representative within the water, energy, and climate change field or within the study area.

Your involvement is voluntary and requires you to participate in an interview (one-on-one, telephonic or written response) conducted by the researcher. The interview is expected to last not more than 2 hours and semi-structured questions are used. All your answers will be treated as confidential and used strictly for this research. However, due to the focus of this research, your institution\organization\department may be identified in any of the reports emanating from this research. Your name or position will not appear in the report and pseudonyms will be used to prevent identity. No form of treatment\payment will be for your participation in the research. You may opt not to take part or withdraw during the research and no form of penalty will be imposed against you. Your participation can only be confirmed by signing the formal consent form provided by the researcher, which will include your consent regarding usage of audio and photography.

The outcomes of the study will be reported in the form of a thesis, academic journal, or at seminars or conferences. A copy of the report or summary shall be made available to participants upon request.

Please contact researcher, supervisors or university's ethics coordinator for further clarity.

Researcher: Steven Matome Mathetsa Tel: 072 720 4491\071 399 6088\012 421 3025 Email: MathetSM@eskom.co.za\Stevenmathetsa@gmail.com Signature:	**Ethics Coordinator**: Shaun Schoeman Tel: 011 717 1408 Email: shaun.schoeman@wits.ac.za
Supervisor: Professor Danny Simatele Tel: 011 717 6521\083 383 6884 Email: danny.simatele@wits.ac.za	**Co-Supervisor:** Dr Isaac Rampedi Tel:0115592425\0833969862 Email: isaacr@uj.ac.za

C. PARTICIPANTS INFORMATION SHEET (FOCUS GROUP DISCUSSION)

School of Geography, Archaeology and Environmental Studies

Participant Information Sheet (Focus Group)

Good day

You are herewith invited to participate in an academic research conducted by Steven Matome Mathetsa (Student Number: 1726197), a Doctor of Philosophy (PhD) student at the University of the Witwatersrand's School of Geography, Archaeology, and Environmental Studies.

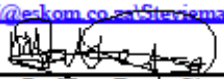
The study research is titled ***Water-Energy-Climate Change nexus in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for sustainable development***. Using Waterberg and Highveld regions for case study, the research aims at applying the IWRM tool in order to understand and improve the management of water resources within the context of an existing water and energy situations in a predicted climate change within the country.

Your selection to participate is based on your role as a professional\expert\researcher\Non-Governmental-Organization\land user\regulator within the water, energy, and climate change field or within the study area.

Your involvement is voluntary and requires you to participate in a focus group discussion coordinated by the researcher. The focus group discussion, guided by semi-structured questions, is expected to last for 4-5 hours and semi-structured questions. All your answers will be used strictly for this research. However, due to the focus of this research, your institution\organization\department may be identified in any of the reports emanating from this research. Your name or position will not appear in the report and pseudonyms will be used to prevent identity. No form of treatment\payment will be for your participation in the research. You may opt not to take part or withdraw during the research and no form of penalty will be imposed against you. Your participation can only be confirmed by signing the formal consent form provided by the researcher and it which will include your consent regarding usage of audio and photography.

The outcomes of the study will be reported in the form of a thesis, academic journal, or at seminars or conferences. A copy of the report or summary shall be made available to participants upon request.

Please contact researcher, supervisors or university's ethics coordinator for further clarity.

Researcher: Steven Matome Mathetsa Tel: 072 720 4491\071 399 6088\012 421 3025 Email: MathetSM@eskom.co.za\Stevenmathetsa@gmail.com Signature: 	**Ethics Coordinator**: Shaun Schoeman Tel: 011 717 1408 Email: shaun.schoeman@wits.ac.za
Supervisor: Professor Danny Simatele Tel: 011 717 6521\083 383 6884 Email: danny.simatele@wits.ac.za	**Co-Supervisor:** Dr Isaac Rampedi Tel:0115592425\0833969862 Email: isaacr@uj.ac.za

1

D. PARTICIPANTS INFORMATION SHEET (PARTICIPANTS OBSERVATION)

School of Geography, Archaeology and Environmental Studies

Participant Information Sheet (Participant Observation)

Good day

You are herewith invited to participate in an academic research conducted by Steven Matome Mathetsa (Student Number: 1726197), a Doctor of Philosophy (PhD) student at the University of the Witwatersrand's School of Geography, Archaeology, and Environmental Studies.

The study research is titled ***Water-Energy-Climate Change nexus in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for sustainable development***. Using Waterberg and Highveld regions for case study, the research aims at applying the IWRM tool in order to understand and improve the management of water resources within the context of an existing water and energy situations in a predicted climate change within the country.

Your selection to participate is based on your role as a professional\expert\researcher\Non-Governmental-Organization\land user\community representative within the water, energy, and climate change field or within the study area.

Your involvement is voluntary and requires you to participate in a participants' observation approach during this workshop\seminar\conference\meeting. The observation is expected to last for the duration of this workshop\conference\seminar\meeting. All observations will be used strictly for this research. However, due to the focus of this research, your institution\organization\department may be identified in any of the reports emanating from this research. Your name or position will not appear in the report and pseudonyms will be used to prevent identity. No form of treatment\payment will be for your participation in the research. You may opt not to take part or withdraw during the research and no form of penalty will be imposed against you. Your participation can only be confirmed by signing the formal consent form provided by the researcher and it will which will include your consent regarding usage of audio and photography

The outcomes of the study will be reported in the form of a thesis, academic journal, or at seminars or conferences. A copy of the report or summary shall be made available to participants upon request.

Please contact researcher, supervisors or university's ethics coordinator for further clarity.

Researcher: Steven Matome Mathetsa Tel: 072 720 4491\071 399 6088\012 421 3025 Email: MathetSM@eskom.co.za\Stevenmathetsa@gmail.com Signature:	**Ethics Coordinator**: Shaun Schoeman Tel: 011 717 1408 Email: shaun.schoeman@wits.ac.za
Supervisor: Professor Danny Simatele Tel: 011 717 6521\083 383 6884 Email: danny.simatele@wits.ac.za	**Co-Supervisor:** Dr Isaac Rampedi Tel:0115592425\0833969862 Email: isaacr@uj.ac.za

1

E. CONSENT FORM (INTERVIEW)

School of Geography, Archaeology and Environmental Studies

Enquiries: GEOGRAPHY, ARCHAEOLOGY

Formal Consent Form (Interview)

I understand that:

Steven Matome Mathetsa has requested an interview for his research titled ***Water-Energy-Climate Change nexus in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for sustainable development.*** The following were explained and understood by me:

- He is Doctor of Philosophy (PhD) student conducting research through the University of the Witwatersrand.
- He has provided the title of his research.
- I have been selected to be interviewed as he is interested in understanding issues related to water, energy, and climate change interactions within the country or study area.
- He indicated that the information received from this interview will be kept on his password-secured computer and used in his final PhD report, academic publication and\or conferences\seminars related to the study.
- The duration of the interview is between 45 to 120 minutes.
- My participation is completely voluntary and if I feel uncomfortable at any point in the interview it will be cancelled without penalty.
- All information I provide will be confidential, used strictly for this research and my name or position will not appear in the report where I can be identifiable.
- Relevant quotes may be used in the research if I provide consent.
- He does not foresee any risks to me or loss of benefits due to my association with this research.
- He will provide a summary of his research findings to me on request.
- Should I have any questions or concerns regarding the research, he has provided me with relevant contact details.



Researcher: Steven Mathetsa
0727204491\0713996088\0124213025
steviemathetsa@gmail.com\steve.mathetsa@eskom.co.za

I hereby agree to participate in the research. Yes ☐ No ☐
I agree that the researcher may quote my answers in his research report. Yes ☐ No ☐
I agree that audio recording system may be used to capture information I provide. Yes ☐ No ☐
I agree that photography may be used during the interview. Yes ☐ No ☐

Signatures:

I_____, agree to participate in Steven Mathetsa's research.
My signature below indicates my consent.

Participant

Signature_____ **Date**_____

F. CONSENT FORM (FOCUS GROUP DISCUSSION)

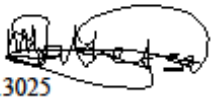
School of Geography, Archaeology and Environmental Studies
Private Bag 3, Wits 2050, South Africa Enquiries: GEOGRAPHY
ARCHAEOLOGY

Formal Consent Form (Focus Group)

I understand that:

Steven Matome Mathetsa has requested a participation in the focus group discussion for his research titled ***Water-Energy-Climate Change nexus in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for sustainable development.***
The following were explained and understood by me:

- He is Doctor of Philosophy (PhD) student conducting research through the University of the Witwatersrand.
- He has provided the title of his research.
- I have been selected to participate in the focus group discussion as he is interested in understanding issues related to water, energy, and climate change interactions within the country or study area.
- He indicated that the information received from this focus group discussion will be kept on his password-secured computer and used in his final PhD report, academic publication and\or conferences\seminars.
- The duration of the discussions is between 4 to 5 hours while focus group discussions may be for the time scheduled.
- My participation is completely voluntary and if I feel uncomfortable at any point in the discussions, I may withdraw without penalty.
- All information I provide will be strictly used for the purpose of this research and my name or position will not appear in the report where I can be identifiable.
- Relevant quotes may be used in the research if I provide consent.
- He does not foresee any risks to me or loss of benefits due to my association with this research.
- He will provide a summary of his research findings to me on request.
- Should I have any questions or concerns regarding the research, he has provided me with relevant contact details.



Researcher: Steven Mathetsa
0727204491\0713996088\0124213025
steviemathetsa@gmail.com\steve.mathetsa@eskom.co.za

I hereby agree to participate in the research. Yes ☐ No ☐
I agree that the researcher may quote my answers in his research report. Yes ☐ No ☐
I agree that audio recording system may be used to capture information provided. Yes ☐ No ☐
I agree that photographs may be used to capture information provided. Yes ☐ No ☐

Signatures:

I_____, agree to participate in Steven Mathetsa's research.
My signature below indicates my consent.

Participant

Signature_____ **Date**_____

G. CONSENT FORM (PARTICIPANTS OBSERVATION)

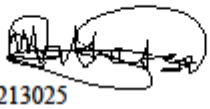
School of Geography, Archaeology and Environmental Studies

Formal Consent Form (participants' observations)

I understand that:

Steven Matome Mathetsa has requested an interview for his research titled ***Water-Energy-Climate Change nexus in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for sustainable development.*** The following were explained and understood by me:

- He is Doctor of Philosophy (PhD) student conducting research through the University of the Witwatersrand.
- He has provided the title of his research.
- As a delegate at the workshop\conference\seminar\meeting, I have been selected to be form part of his participants to be observed during as he is interested in analysing participants discussions around issues related to water, energy, and climate change interactions within the country or study area.
- He indicated that the information received from this participant observations will be kept on his password-secured computer and used in his final PhD report, academic publication and\or conferences\seminars related to the study.
- The observations will be undertaken throughout the duration of this workshop\seminar\conference\meeting.
- My participation is completely voluntary and if I feel uncomfortable at any point in the observations I will request that I withdraw cancelled without penalty.
- All information I provide will be used strictly for academic purpose and my name or position will not appear in the report where I can be identifiable.
- Relevant quotes may be used in the research if I provide consent.
- He does not foresee any risks to me or loss of benefits due to my association with this research.
- He will provide a summary of his research findings to me on request.
- Should I have any questions or concerns regarding the research, he has provided me with relevant contact details.



Researcher: Steven Mathetsa
0727204491\0713996088\0124213025
steviemathetsa@gmail.com\steve.mathetsa@eskom.co.za

I hereby agree to participate in the research. Yes ☐ No ☐
I agree that the researcher may quote my answers in his research report. Yes ☐ No ☐
I agree that audio recording system may be used to capture information I provide. Yes ☐ No ☐
I agree that photographs may be used during the observations. Yes ☐ No ☐

Signatures:

I_____, agree to participate in Steven Mathetsa's research.
My signature below indicates my consent.

Participant

Signature_____ **Date**_____

H. QUESTIONNAIRE

RE: Discussion

Research Title: ***Water-Energy and Climate Change Nexus (WECC) in South Africa: Application of the Integrated Water Resource Management (IWRM) approach for Sustainable Development***

Dear participant

These semi-structured questions are designed for the research project aimed at *investigating the extent to which the WECC nexus can be understood in South Africa*. This is done in order to ensure that the sustainable development risks associated with WECC are mitigated within the country.

Thank you for taking time to form part of this discussion session. The entire discussion should take you about 30-60 minutes to answer.

For clarity, please contact:

- **Researcher: Steven Mathetsa (PhD student –University of Witwatersrand)**
  Contact details: 0727204491/0713996088/mathetsm@eskom.co.za

- **Supervisor: Professor Danny Simatele (Associate Professor at University of Witwatersrand)**
  Contact details: 011 7176516/ 0833836884/Danny.Simatele@Wits.ac.za

- **Co-Supervisor: Professor Isaac Rampedi (Associate Professor at University of Johannesburg)**
  Contact Details: 011 559 2429/ 0833969862/ isaacr@uj.ac.za

- **Industrial mentor: Mr Gerhard Gericke (Senior Consultant: Applied Chemistry and Water at Eskom)**
  Contact Details: 011 629 5721/ 083 270 1630/ gerhard.gericke@eskom.co.za

SECTION 1: DEMOGRAPHIC INFORMATION

Kindly complete demographic information in the table below:

Participant's institutional association (e.g. Government/Authority/Regulator, Non-governmental organization, researcher\academic, Expert\Specialist (Energy, climate change, water resources, environmental), landowner, community member, researcher	
Designation/Position	
Educational profile	
Years of experience in the field	
Contact details (Optional)	
Gender (Optional)	

SECTION 2: DISCUSSION QUESTIONS

- What are the critical interactions between water, energy and climate change? Are those interactions being fully considered during decision making?

  ……

- Who are the key stakeholders involved in WECC?

……

- Are there necessary qualitative data available to understand the WECC nexus?

……

- Are there necessary quantitative data available to understand WECC nexus?

……

- How can coordination and collaboration between all role players in policy, research and development within WECC be encouraged?

……

- What are the impacts of water policies and regulations on energy supplies and demands?

……

- What is the impact of energy policies and regulations on water demands and availability?

……

- How do policies aimed at climate mitigation and adaptation effect policies developed in the energy and water sector, and visa-versa?

……

- What kind of regulatory framework is necessary and feasible to minimise negative trade-offs in the WECC in both public-sector planning and private enterprises?

……

- What new knowledge and skills are needed amongst public institutions in order to manage complex issues associated with WECC nexus?

……

- What are the energy, water, and climate change footprint in our processes?

……

- How can we reduce our footprint on the above?

……

- What is the likely impact on the new regulations, standards and incentives related to WECC nexus on the production processes and how best can we plan for them?[6]

……

- What role can the organisation play in the development of new policies and frameworks aimed at minimising the WECC footprint?[7]

……

- How aware or involved is the community at large on the WECC nexus and what evidence supports this?

……

- Are there an effort to implement the outcomes of the research and development by either industries or policy-makers?

……

General Comments:

……

[6] Mostly applicable to industries
[7] Mostly applicable to industries

I. PUBLISHED ARTICLE 1

Journal of Energy in Southern Africa

Volume 30 Number 3
August 2019

Perspectives on integrated water resource management and its relevance in understanding the water-energy-climate change nexus in South Africa

Steven Matome Mathetsa[1,4*], Mulala Danny Simatele[1,2], Isaac T. Rampedi[3], Gerhard Gericke[4]

1 School of Geography, Archaeology and Environmental Studies, Department of Geography and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

2 School of Science and Technology, Rusangu University, Monze Campus, Monze, Zambia

3 Department of Geography, Environmental Management & Energy Studies, University of Johannesburg, Johannesburg, South Africa

4 Risk and Sustainability Division, Research Testing and Development, Eskom Holdings SOC, 5 Lower Germiston Road, Rosherville, Cleveland, South Africa.

ORCIDs: Mathetsa: https://orcid.org/0000-0001-5669-3991 Simatele: https://orcid.org/0000-0002-2161-1586

Rampedi: https://orcid.org/0000-0002-1868-8486 Gericke: https://orcid.org/0000-0001-7401-4091

Abstract

It is increasingly acknowledged that the water-energy-climate change (WECC) nexus is one of the synergies that pose a significant risk to achievement of sustainable development goals (SDGs), specifically numbers six, seven and thirteen. There are suggestions that climate change outcomes such as increased temperature and drought episodes have implications for water availability, which in turn affects energy production in countries dependent on hydropower, pump-storage or coal-generated electricity, including South Africa. This development therefore calls for improved understanding of how to effectively manage the challenges that arise from this nexus, to mitigate the impacts it may have on achieving the associated SDGs. This study, which is based on an in-depth appraisal of existing developments, assessed the potential of the integrated water resource management framework in understanding the WECC nexus and its implications for South Africa's sustainable development endeavours, particularly in the context of water resource management and utilisation. The study revealed South Africa's lack of integrated, effective, and efficient institutions and policy framework to comprehensively manage the challenges emanating from this nexus. It identified an urgent need to develop systems and processes through which South Africa can handle the challenges as well as capture the benefits that may be obtained from this nexus.

Keywords: *climate change, energy security, water resource management, sustainable development*

Journal of Energy in Southern Africa 30(3): 11–21
DOI: http://dx.doi.org/10.17159/2413-3051/2019/v30i3a5654

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International Licence
Published by the Energy Research Centre, University of Cape Town ISSN: 2413-3051
https://journals.assaf.org.za/jesa

Sponsored by the Department of Science and Technology

* *Corresponding author: * Tel: +27 72 720 4491;*
email: steviemathetsa@gmail.com

1. Introduction

The sustainable development concept is premised on the assertions revolving around the objective to meet the needs of the present generation without compromising those of the future (Omer, 2008; Masters, 2009; Mathetsa, 2016). This definition embeds within itself the importance of identifying strategies and systems aimed at supplying and conserving resources within the socio-economic developmental needs of communities (United Nations [UN], 1972; 1992; Kubiszewski and Cleveland, 2012). This focus is regarded as a way of establishing a balanced system on how to effectively achieve economic and social progress within the limits of environmental sustainability, as well as aligning national development to the targets embedded in the sustainable development goals (SDGs). Increased global and local demands for resources in both domestic and industrial use have, however, exerted immense pressure on natural resources to a point of untenable management. Chilundo et al. (2008) and Brazilian et al. (2011) have pointed out factors, such as a rapid increase in population growth, industrialisation and urbanisation, that are driving natural resources towards devastation. These remarks, therefore, instigate a re-examination of how resources are used and safeguarded in such a manner that SDGs are achieved.

As the supply of water and energy resources emerges as one of the central themes of modern human life, their global demand is expected to increase as the need to attain SDGs intensifies. The Global Water Partnership (2000) and Al Saidi (2017) have pointed out that water scarcity in most global communities requires that their security be treated as a main topical issue within sustainable development at large. It is, however, observed that obstacles such as rising climate vulnerabilities exacerbate water scarcity (Natural Resource Defence Council, 2010; Ziervogel et al., 2014; DeNicola et al., 2015; Nhamo et al., 2018), thus raising profound concerns as to how a sustainable supply of critical resources can be attained. This underlines the persistent necessity for society globally to strive for a balanced system across the management of natural resources.

Given the threat that shortages of resources are posing to SDGs, it is widely reported that food and energy production are amongst the essential socio-economic sectors most vulnerable to these constraints (Carter and Gulati, 2014; Carpenter, 2015; Rasul and Sharma, 2016; Mabhaudhi et al., 2016). The extent of this vulnerability is likely to be experienced mainly in countries such as South Africa, where water availability and supply drives both electricity generation and food production, while energy is one of the most critical drivers of water treatment and distribution (Carpenter, 2015; International Energy Agency, 2016; Nhamo et al., 2018). This points to the interconnection and interdependency between water and energy systems, which most developing countries are struggling with and striving to supply on a reliable and sustainable basis.

In many sub-Sahara African (SSA) countries, the interlinkage between water and energy remains significant in the region, particularly in countries such as South Africa where coal-combustion is still the main driver for electricity production. Energy generation through coal-combustion, however, is one of the biggest contributors to human-induced climate change through the release of greenhouse gases (Intergovernmental Panel on Climate Change, 2007; Omer, 2008) which is widely perceived to be threatening human existence and exerting enormous pressure on limited water resources (Mukheibir, 2008; Dennis and Dennis, 2012; Nkhonjera, 2017). These considerations further highlight the coupling between the systems of water, energy and climate change – the water-energy-climate change (WECC) nexus. Its occurrence in South Africa corroborates the findings of Head and Cammerman (2010) who argued that most global communities, particularly those at developing stages, are likely to be faced with the WECC nexus. These dynamics call for critical questions relating to the WECC management and its socio-economic and ecological interactions, in countries such as South Africa which have been identified as climate change hotspots (Ziervogel et al., 2014; DeNicola et al., 2015; Nhamo et al., 2018).

Despite the complex linkage of systems of water, energy and climate change, several studies have concurred that challenges such as the pragmatic lack of coordinated planning, policy integration, and a systematic approach impedes effective management of WECC and its components (Cammerman, 2009; Hussey and Pittock, 2012; Rasul and Sharma, 2016; Mabhaudhi et al., 2016; Stein et al., 2018; Nhamo et al., 2018). This challenge deepens doubts about the attainment of SDGs linked to these components. In developing countries such as South Africa, the risks associated with WECC are likely to be felt, as the lack of adequate and integrated management of water, energy, and climate change systems is intense (Scott et al., 2011). This necessitates the need to establish contemporary approaches that will broaden understanding of this nexus and effectively manage it in a way that positively contributes to sustainable development.

Within the WECC nexus, water is regarded as the central component (Walmsley et al., 2001; Prasad et al., 2012; Jagerskog et al., 2014). Its dominant role across various societal needs suggests that its sustainable management would benefit energy security while adapting to climate change. This observation supports the need for a shift in

paradigms and adopting approaches which would facilitate sustainable systems of water resource management in order to minimise socio-economic and environmental risks associated with the WECC nexus. Studies within the sustainability sector have proposed different approaches for protecting and utilising water, including integrated water resource management (IWRM). The GWP (2000) and Leendertse et al. (2008), for example, found that this framework's ability to raise sufficient awareness, while promoting practical guidelines in a systematic and integrated approach, makes it one of the most useful tools available to promote sustainable water resource management. Considering the dire state of water resources in South Africa, there is a need to explore the potential and value of implementing the IWRM framework to address WECC conundrum.

The present study examined developments in the WECC nexus to explore its effective management through an integrative and holistic approach. Conducting a review on an emerging and complex subject such as WECC is a crucial contribution to providing dependable and general information regarding this nexus while identifying gaps that should be addressed. Bless et al. (2013) suggested that a review of this nature involves searching and studying of previous and current developments on the investigated problems without raising any controversy. The present study also explored the IWRM framework with the view to utilising it as a tool to widen the understanding and promotion of effective management of the WECC nexus in South Africa.

2. Methodology

This study examined the international developments, with an emphasis on SSA, especially South Africa, in water, energy and climate change systems, and thus the WECC nexus and IWRM framework. To this extent, a rapid appraisal of empirical academic and non-academic literature such as project and industry reports, books and presented papers was conducted. Additional developments were obtained from the Water Research Commission, a South African-based research institute that conducts and publishes studies within the water and environmental fields in the Southern Africa region. With a focus on themes such as sustainable water resource management, energy security, and climate change impacts, the criteria for inclusion in the appraisal were based on global, regional and local studies focusing mostly on different nexus types such as WECC, water-energy (WE) and water-energy-food (WEF). This methodology was influenced by suggestions of the limited work done on WECC in South Africa, which is intensified by a lack of broadened knowledge, and fragmented policy approach on the nexus. This appraisal was corroborated by extensive verbal interaction with a specialist within the field of WECC with the intention to gain further information on this nexus and its challenges within the SSA region.

3. Results and discussion

3.1 Contextual developments on WECC nexus

The SDGs numbers six, seven and thirteen underline the need for global communities to maximise the reliable supply of water and energy, while combating climate change and its related impacts (UN, 2015). Communities in SSA are faced with similar expectations. In South Africa for example, Winkler (2006) expressed the view that most of the country's socio-economic developmental needs could be achieved through an increased supply of energy. This, however, must be done within the parameters of safeguarding natural resources such as water, land and atmosphere. Although the need to address societal and ecological imperatives is intensifying, studies have mentioned the complex interlinkage between some of the key features of modern life as one of the synergies halting their attainment (Head and Cammerman, 2010; Bazilian et al., 2011; Pahl-Wostl et al., 2018). Among those interlinkages, the complex connection between the systems of water, energy, food and, more recently, with the consideration of climate change, give rise to different forms of nexus. With uncertainties emerging from these nexus, concerns over the reliable supply of resources such as food, water, and energy, as well as their contribution towards climate change intensify. On the other hand, climate change impacts the availability of these resources in numerous forms.

Recent studies have made contrasting reports about when and how the nexus within the sustainable management discourse emerged (Siddiqi and Anadon, 2011; Conway et al., 2011; Muller, 2015; Pahl-Wostl et al., 2018; Simpson and Jewitt, 2019). While initial studies around the nexus are mostly limited to water and energy interactions and in some instance incorporate food production, Siddiqi and Anadon (2011) suggested that the need to acknowledge and understand the WE nexus was recognised as early as 1994. Muller (2015), however, asserted that recognition of such interlinkages arose as early as the 1970s. Irrespective of when it emerged, the socio-economic influence of the nexus encouraged its discussions at various global gatherings during the 2000s. For example, conferences such as the Gleneagles G8 Environmental Ministers' meeting in 2007, the Davos World Economic Forum in 2008, and Bali's United Nations Framework Convention on Climate Change meeting in 2008 resolved to strengthen the understanding and management of the water and energy interactions (European Cooperation in Science and Technology [COST], 2009; Cammer-

man, 2009). Furthermore, the Bonn Nexus conference in 2011 reflected mainly on the interactions of water and energy together with food production, resulting in more studies embracing the triangular WEF nexus (Conway et al., 2011). These observations fortified the discussions and investigations around various types of nexus to gain momentum in both policy and research perspectives.

Until recently, most studies did not consider the impact of climate change on the nexus configurations. Climate vulnerability studies prompted global researchers to consider its role towards food, energy and water security. Studies in countries such as the United States (US), China, Spain and Australia were the first to focus mainly on the WE with brief considerations of climate change influence. For example, Hussey and Pittock (2012) found that the WE study conducted in the US in 2006 was one of the initial researches that embraced climate change role in the nexus. This and other subsequent developments resolved to fully incorporate climate change in coupled triangular interactions of water and energy.

Despite the emerging interest in the WECC nexus and its sustainable developmental impacts, studies on the in-depth understanding of this nexus and its consequences are still limited. This is confirmed by limited documented information on this nexus both at a global and regional level. Platonova and Leone (2012) and Yillia (2019) pointed out this as a concern for developing countries, particularly those in the SSA. Nkhonjera (2017) suggested that this region's lagging behind on climate change and its influential role on other sectors such as water and energy is attributed to uncertainties in climate and hydrological modelling, lack of financial resources and political will to develop and implement policy, particularly in developing regions. This raises resistance in recognition of paradigms such as WECC as well as policy development within them and is confirmed by recent studies in the SSA countries of Cameroon, Kenya and South Africa where WE and WEF nexus are still at the centre stage (Platonova and Leone, 2012; Ackom, 2014; Carter and Gulati, 2014; Mabhaudhi et al., 2016; Wakeford, 2017; Yillia, 2019).

The interlinkage between water, energy and climate change is a complex one, accentuated by interdependencies in multi-sectoral systems. For example, studies by Carpenter (2015) and Copeland and Carter (2017) maintained that, while a substantial part of the global energy production systems heavily depends on water availability for various processes such as raw material extraction and cooling, the treatment, supply and usage of water, particularly in domestic and industrial practices, is an energy-dependent process. This interdependency is intensified by the distance of water users from water resources, which exacerbates energy needs in the water value chain. Conversely, the global overreliance of energy production on the fossil fuel combustion process results in the emission of greenhouse gases, which accelerates climate change. Despite climate change's influence on energy generation processes such as cooling, Ziervogel et al. (2014) and Kundzewics et al. (2016) concurred that its role in water availability is severe, as occurrences such as varying temperature, floods, precipitation and drought affect the hydrological cycle. These varying climatic conditions and other impacts such as water pollution exacerbate water shortages, thus putting pressure on energy production and its associated sectors. The severity of this water, energy and climate change interdependency is experienced on a global scale already. For example, studies by Siddiqi and Anadon (2011) and Carpenter (2015) pointed out that some countries in Europe, South America, and Asia had to reduce their electricity production because of water shortages intensified by climate variabilities, particularly drought and increased temperatures.

The SSA, a rapidly developing region characterised by prolonged water shortages because of its semi-arid geographical characteristics and increasing energy demands, is not resistant to WECC and its challenges. For example, while the region is striving to meet modern energy and water demands, Serdeczny et al. (2015) observed that this region is one of those where climate change outcomes will most be felt, in a number of sectors. Furthermore, Prasad et al. (2012) and Conway et al. (2015) indicated that drought and freshwater shortages in hydropower-dependent countries such as the Democratic Republic of Congo, Lesotho, Malawi, Kenya, Zimbabwe, and Zambia resulted in disruptions to the supply of energy. Despite these noticeable impacts of the WECC on the region's socio-economic developmental needs, it is observed that WE and WEF are still at the centre stage of nexus researches. Ackom (2014), Stein et al. (2018) and Yillia (2019), however, suggested that the region should intensify how it considers climate change's role on WE and WEF, thus presenting the SSA with opportunities to look at prospects of managing WECC effectively.

South Africa is one of those SSA countries likely to be affected by risks emanating from WECC. For example, despite the country's well-documented water scarcity status, approximately 90% of the electricity is generated from water-reliant coal-combustion, nuclear, hydropower and pump-storage technologies (Eskom, 2016). Being one of the epicentres of the national developmental plans, power generation is supplied with 2% of the freshwater available in the country with reliable assurance, second only to the agricultural sector (Eskom, 2012; Department of Water and Sanitation [DWS], 2014). The country is, however, ranked among the top

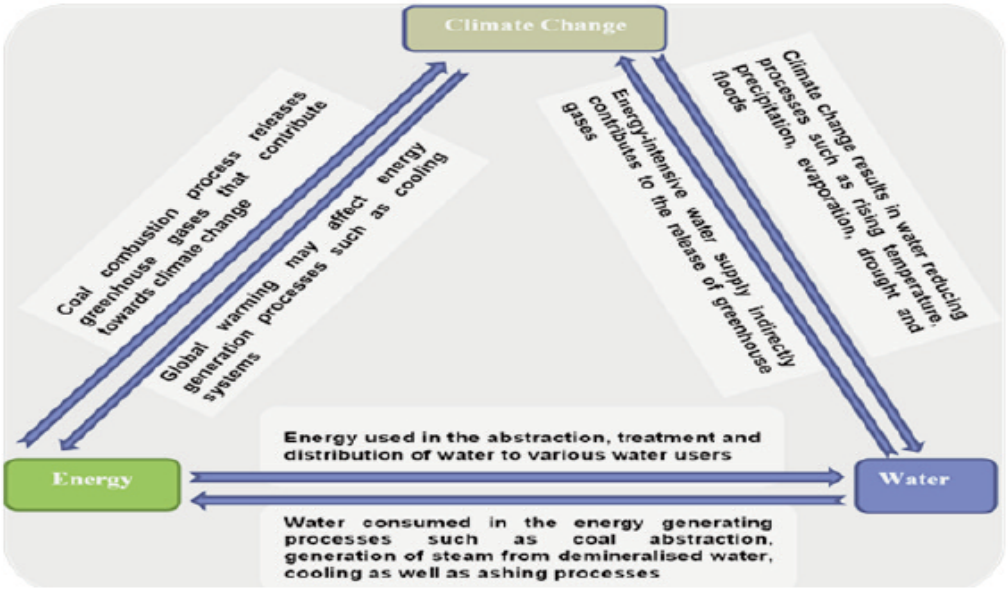


Figure 1: Coupled interactions between water, energy and climate change in South Africa.

producers of greenhouse gases, largely because of emissions from the power generation sector, specifically the coal-combustion technology (Carter and Gulati, 2014). The upsurge of climate change and influence from other anthropogenic activities such as urbanisation, exert pressure on already constrained water and energy resources. These observations show how the systems of water, energy and climate change are inextricably interconnected in the country, as elaborated in Figure 1. However, just like a situation at the global and regional context, the country has demonstrated a lack of knowledge and integration with regard to managing the WECC and its risks. However, recent studies such as those by Mabhaudhi et al. (2016) and Nhamo et al. (2018) concurred on the need to effectively manage the nexus in a holistic and integrated manner. The present study, therefore, suggests the need for the country to broaden its understanding of the WECC and to initiate discussions such as policy integration to combat the risks associated with this nexus.

3.2 Governance on the WECC nexus

Earlier investigations on WECC highlighted that partial understanding of this nexus results in a 'silo' approach, especially from the governance perspective (Cammerman, 2009; Head and Cammerman, 2010). Lack of a coordinated planning system, practices and policy development between the sectors of water, energy and climate change is a concern in many countries. Investigations are, however, gaining momentum elsewhere to minimise these governance setbacks (Goldstein et al., 2008; Energy and Water Integrated Act [EWIA], 2009). For example, the US study on WE recommended the development of an integrated policy on water and energy (Goldstein et al., 2008). In response, the EWIA policy was developed with the view to direct the US towards improving governance of the nexus through an in-depth analysis of the impact of energy development and production on the country's water resources (EWIA, 2009). Despite not being signed into law, this strategy encouraged other parts of the US and other countries to broaden investigations of various nexus studies in an integrated manner. For example, subsequent investigations and publications of reports such as the 'Water-energy nexus: Challenges and opportunities' (United State Department of Energy [US DoE], 2014) show efforts to promote a systematic, integrated and proactive way to address the nexus to ensure a reliable supply of energy under different water and climate constraints.

Despite such efforts and progress on incorporating all nexus components in planning, some countries still lag behind. South Africa is one of those that still approach governance of water, energy and climate change policy and implementation in isolation. Studies by Mabhaudhi et al. (2016) and Nhamo et al. (2018) showed that sectoral approaches driven by sector mandates which seldom refer to each other, are cause for concern about effective governance of these systems. This is despite the country's adoption of the National Environmental Management Act, Number 107 of 1998, which endorses the integrated environmental management approach as one of its objectives. This policy segmentation demonstrates a fragmented approach and lack of collective effort from the key stakeholders in the management of energy, water and climate change. For example, with policies such as the National Water Resource Strategy (NWRS) in place, the DWS is mandated to ensure that man-

agement and protection of water resources in South Africa are fulfilled (DWS, 2014). Water policies mostly acknowledge the impact of climate change on water resources, but without providing a plan as to how these will be dealt with. Policies relating to water resources' adaptative and resilient strategies on climate change are developed by the Department of Environmental Affairs (Department of Environmental Affairs [DEA], 2015). This is a concern, as there would be overlap in terms of implementation. Furthermore, despite assurances on freshwater supply for the energy sector, water resource constraints highlight the need for integrated planning to secure water supply for power generation. However, recent delays in aligning water supply to energy generation raise gaps in terms of policy planning and implementation between these sectors. Similar misalignments are observed in energy planning. For example, despite proposing a mix that will decarbonise power generation sector with reduced water consumption, the 2010–2030 Integrated Resource Plan (IRP) highlights that 65% of the country's energy will still be generated using the water-reliant coal combustion process (DoE, 2010). This policy is silent on how the power generation sector will be reliably supplied with water and provides little suggestions on the improvement of water management at the operational level.

Furthermore, the IRP offers no strategy as to how the energy sector will reduce their greenhouse gas emissions from coal-fired power stations, except through decommissioning of power plants. Additionally, Madhlopa et al. (2016) noted that the IRP hardly addresses the water impacts resulting from the lifecycle of energy production, mainly raw material extraction such as coal mining, which is seen as the responsibility of the Department of Mineral Resources. The National Climate Change Response Policy was drafted to manage challenges emanating from climate change (DEA, 2015). The policy further recommended that the adaptation strategies be implemented within the NWRS, while climate mitigation strategies in the energy sector include the reduction of carbon emissions (DEA, 2015). Trollip and Boulter (2017), however, contended that this policy can be attributed to lack of coordination and alignment between the different role players in DEA, DWS and DoE.

These observations point to a critical gap emerging from the governance of WECC components, where governmental structures still operate in a segregated manner in South Africa. This gap owes much to the unaligned institutional and policy framework within which a coordinated and integrated approach towards management of water and energy resources in the context of climate change can be pursued. Several studies suggest delineating this complex issue to effectively address it. For example, in addressing myriad water issues, developing a consensus that proposes a shift towards 'nexus thinking' when addressing issues related to the WECC is an imperative one (Global Donor Platform for Rural Development, 2017; Taylor-Wood and Fuller, 2017). Reynolds and Cranston (2014) further suggested that nexus thinking can respond to the risks associated with different configurations. Nexus thinking is intended to promote viewing a specific problem from different angles to create an understanding of the bigger picture holistically and systematically while addressing other associated systems. Therefore, considering its centrality in WECC, an approach where water-related challenges are addressed while equally considering issues arising from energy and climate change could be an effective solution for this nexus. In Australia, studies by Cammerman (2009) and Head and Cammerman (2010) suggested that this integrated approach could be achieved through the implementation of the IWRM framework, which emerges from the water management perspective.

3.3 Towards the integrated approach

While the developments on nexus are still at an infant stage, research conducted on sustainable water resource management resulted in the paradigms such as the IWRM, which focusses on addressing complex systems involving water (GWP, 2000; Pollard and Du Toit, 2008; Heldt et al., 2017). This research stimulated suggestions that effective management of water should be at the apex of WECC as it may influence how to minimise the nexus risks to socio-economic development (Prasad et al., 2012; Jagerskog et al., 2014). Cammerman (2009), for example, asserted that lack of broadened understanding of the complexities and interactions around WECC may result in unsustainable management and utilisation of water, which crosscuts most sectors, including food production. The question raised in this study is, however, how the efficient management of water resources presents an amplified system that builds their resilience towards climate change, thus easing energy security and the associated sustainable development threats.

While different approaches towards managing water may be applicable, Cammerman (2009) and Bindra et al. (2013) contended that the IWRM approach is one of the useful tools that can endorse, structure and mutually enforce management of this resource holistically and sustainably. Despite this framework being around for some time, Biswas (2008) and Nesheim et al. (2010) maintained that it only started being amplified by scientists and the GWP around the 1990s, and was strengthened only around the early 2000s. Initial discussions at various gatherings such the Dublin's UN-Water and Environment Conference in 1992, Rio's World Summit in 1992, Bonn's International

Conference on Freshwater in 2001, and the Johannesburg World Summit on Sustainable Development in 2002, intensified the need to implement this framework for improved water resources management. Furthermore, the usefulness of this framework was recognised by at least 65% of countries which adopted it prior to the Rio Plus Conference in 2012 (Al-Saidi, 2017).

According to GWP (2000), this framework can shed light on how to develop regulations and regional plans for water governance in an integrated manner. This will ensure effective environmental management while defining institutional roles and stakeholder participation within the management of water resources. Studies within water resource management, however, show that this framework continues to receive criticism from some practitioners and scientists (Biswas, 2004; Fulazzaky, 2014; Heldt et al., 2017). For instance, Biswas (2004, 2008), found that the IWRM has demonstrated a lack of technical and institutional ability to address water resource challenges, thus resulting in setbacks regarding how it is implemented. This observation raises concern within the water fraternity as to whether it is a practical tool to provide solutions for current and future challenges. Biswas (2008) further emphasised that this IWRM is not effective enough when applied across varying sectors such as agriculture and energy or even at a macro scale. Other studies, however, presented a different observation, arguing that IWRM can promote integrated management across different sectors such as energy, food production and water (Leendertse et al., 2008; Nesheim et al., 2010). Bringing together different water users with a common goal promotes integration as all views have the potential to be considered in planning and policy development. Doubts about the effectiveness of IWRM resulted in other nations opting against its adoption. For example, some European countries opted to implement the European Union Water Framework Directive, a policy developed to provide alternative solutions to their water challenges (Heldt et al., 2017).

In many developing nations, such as those in SSA, lack of participation and political will still weaken IWRM's implementation. Muller (2015) raised factors such as the focus on growing the economy as well as climate vulnerability as some of the challenges impeding IWRM implementation in these nations. This underlines the need for a more robust and effective approach if water resource management improvements are to be attained. In South Africa, notably, challenges arising from coordination and policy implementation threaten the country's already stressed water resources to a point where its availability to sectors such as energy and food production cannot be guaranteed. Funke et al. (2007), however, maintained that, through a holistic and systematic manner presented in IWRM, this framework is a necessity if the country is to address its short-term risks and achieve long-term security of water resources, particularly those associated with scarcity and inequitable distribution, as well as mismatches identified in agriculture, industry and energy sector located on heavily concentrated water demand regions such as the highveld in Mpumalanga. Funke et al. (2007) and Karar (2008), however, indicated that the country's application of IWRM is still limited to a water perspective or policy development within this sector.

Given that WECC components are governed in segregation despite the interlinkages, can this be mitigated by the IWRM's ability to influence governance through the promotion of a multi-participatory approach as well as consideration of different driving forces and their linkages? Cammerman (2009) suggested that this framework's proactive risk-based approach is one of its strengths, one that can promote an integrated approach on policies and strategies, while addressing associated challenges, particularly towards the socio-economic development agenda. This is despite it arising from the water resource management perspective.

4. Conclusions

This study examined developments in one of the emerging paradigms that threaten the achievement of sustainable development goals: water-energy-climate change (WECC) nexus. The study revealed two key findings. Firstly, it is evident that studies of the WECC nexus are still limited internationally. Most nexus studies have, to date, focused mainly on water-energy and water-energy-food configurations. A similar observation is made in South Africa where there is an inextricable linkage between systems of water, energy and climate change. Secondly, despite gaps being identified in the management of different nexus configurations, South Africa still lack policy integration. Currently, various government departments such as the Department of Water and Sanitation, Department of Environmental Affairs and Department of Energy generally address sectoral requirements instead of adopting an integrated approach. The study contributes towards closing the existing knowledge gap on WECC, thus assisting South Africa to understand and address myopia about the relationship between water, energy, and climate change, and promote discussions on an integrated approach in the development of institutional and policy framework.

Acknowledgments

Thanks to Eskom's Research, Testing and Development division for funding the study. The views presented in this paper are those of the authors and do not necessarily reflect the views of Eskom.

Author roles

S. Mathetsa: Main author and researcher. Data collection and write-up.
M. Simatele: PhD supervisor, reviewer.
I. Rampedi: PhD co- supervisor, reviewer.
G. Gericke: Industrial mentor, reviewer.

References

Ackom, E. 2014. Energy, water and climate nexus: A case study of Cameroon. In Nexus 2014: Water, food, and energy. Online: http://orbit.dtu.dk/files/128129576/nexus_2014_abstract_book.pdf (Accessed: 14 March 2018). https://doi.org/10.1115/imece2014-36502

Al-Saidi, M. 2017. Conflicts and security in integrated water resource management. *Environmental Science and Policy* 73: 38-44. https://doi.org/10.1016/j.envsci.2017.03.015

Bindra, S. P., Hamid, A., Salem, H., Hamuda, K. and Abulifa, S. 2013. Sustainable integrated water resources management for energy production and food security in Libya. *Procedia Technology* 12: 747–752. https://doi.org/10.1016/j.protcy.2013.12.558

Biswas, A. K. 2004. Integrated water resources management: A reassessment. *International Water Resources Association* 29(2): 248-256. https://doi.org/10.1080/02508060408691775

Biswas, A. K. 2008. Integrated Water Resources Management: Is it working? *International Journal of Water Resource Development* 24(1): 5-22.

Bless, C., Higson-Smith, C. and Sithole, S. l. 2013. Fundamentals of social research methods: an African perspective. 5th edition. Juta & Co. South Africa.

Brazilian, M., Rogner, H., Howells, M., Hermann, S., Douglas, A., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, S. J. R. and Yumkella, K. K. 2011. Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy* 39: 7896-7906. https://doi.org/10.1016/j.enpol.2011.09.039

Cammerman, N. 2009. Integrated water resource management and the water, energy, climate change nexus: a discussion report. Masters Thesis, University of Queensland, Australia.

Carpenter, A. M. 2015. Water availability and policies for the coal power sector. *IEA Clean Coal Centre*. Report No. ccc/256. United Kingdom.

Carter, S. and Gulati, M. 2014. Climate change, the food energy water nexus and food security in South Africa: Understanding the food energy water nexus. *WWF-SA*: 1-17. https://doi.org/10.1115/imece2014-36502

Chilundo, M., Kelderman, P. and O'Keeffe, J. H. 2008. Design of a water quality monitoring network for the Limpopo River Basin in Mozambique. *Physics and Chemistry of the Earth* 33: 655-665. https://doi.org/10.1016/j.pce.2008.06.055

Conway, D., Van Garderen, E. A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Osborn, T., Ringler, C., Thurlow, J., Zhu, T. and Dalin, C. 2015. Climate and Southern Africa's water–energy–food nexus. *Nature Climate Change* 5(9): 837-846. https://doi.org/10.1038/nclimate2735

Copeland, C. and Carter, N. T. 2017. Energy-water nexus: The water sector's energy use. Congressional Research Service Report prepared for members and committees of congress, 24 January 2017.

European Corporation for Science and Technology (COST). 2009. The energy-water nexus: Managing the links between energy and water for a sustainable future. COST explanatory workshop, Brussels, 19-21 January 2009.

DeNicola, E., Aburizaiza, S. O., Siddique, A., Khwaja, H., and Carpenter, D. O. 2015. Climate Change and Water Scarcity: The Case of Saudi Arabia. *Annals of Global Health* 81(3): 342-353. https://doi.org/10.1016/j.aogh.2015.08.005

Dennis, I. and Dennis, R. 2012. Climate change vulnerability index for South African aquifers. *Water SA* 38(3): 417-426. https://doi.org/10.4314/wsa.v38i3.7

Department of Energy (DoE). 2013. Integrated Resource Plan for electricity: 2010-2030 Revision 2. DoE, Pretoria, South Africa. Online:http://www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (Accessed: 20 February 2018).

Department of Environmental Affairs. 2015. National climate change response policy, White Paper. Pretoria, South Africa.

Department of Water and Sanitation. 2014. National water resource strategy: Water for equitable and sustainable future. Government Printers, Pretoria, South Africa.

Electricity Power Research Institute. 2010. Sustainable water resource management: Case study on new water paradigms, 3. Online:

http://www.ndwrcdp.org/documents/DEC6SG06a/Case%20Studies%20on%20New%20Water%20Paradigm.pdf (Accessed: 20 April 2018).

Energy and Water Integration Act. 2009. S 539 of The Bill: The senate of the United States, 111th congress 1st session. The United States, 5 March 2009.

Eskom. 2012. Water, energy and development: Sustainability group, research, testing and development. Johannesburg, South Africa.

Eskom. 2016. Eskom water management policy. Document identifier: 32-1163. Online:https://hyperwave.eskom.co.za/Eskom/Group%20Capital/Eskom%20Real%20Estate/SHEQ/Environmental%20Management%20System_ISO%2014001/North%20West%20%26%20Free%20State/Free%20State/Bloemfontein/4.4.6.%20Operational%20Controls/Water%20Management/Policy.pdf (Accessed: 18 June 2018).

Fulazzaky, A. M. 2014. Challenges of integrated water resources management in Indonesia. *Water* 6: 2000-2020. https://doi.org/10.3390/w6072000

Funke, N., Oelofse, S. S. H., Hattings, H., Ashton, P. J. and Turton, A. R. 2007. IWRM in developing countries: Lessons from the Mhlatuze catchment in South Africa. *Physics and Chemistry of the Earth* 32: 1237-1245. https://doi.org/10.1016/j.pce.2007.07.018

Goldstein, N. C., Newmark, R. L., Whitehead, D. C., Burton, E., McMahon, J. E., Ghatikar, G. and May, D. W. 2008. The energy-water nexus and information exchange: Challenges and opportunities. *International Journal of Water* 4(1\2): 5-24. https://doi.org/10.1504/ijw.2008.018144

Global Donor Platform for Rural Development. 2017. Online: https://www.donorplatform.org/news-agenda-2030/exploring-the-power-of-nexus-thinking-in-sdgs-implementation.html (Accessed: 01 March 2019).

Global Water Partnership. 2000. Integrated water resources management: Report by Technical Advisory Committee. TAC background papers no. 4, Stockholm, Sweden. Online: https://www.gwp.org/globalassets/global/toolbox/publications/background-papers/04-integrated-water-resources-management-2000-english.pdf (Accessed: 26 June 2017).

Head, B. and Cammerman, N. 2010. The water-energy nexus, a challenge for knowledge and policy. Urban Water Security Research Alliance, Technical report No. 39. Online: http://www.urbanwateralliance.org.au/publications/UWSRA-tr39.pdf (Accessed: 28 March 2018).

Heldt, S., Rodriquez-de-Francisco, J. C., Dombrowsky, I., Feld, C. K. and Karthe, D. 2017. Is the EU WFD suitable to support IWRM planning in non-European countries?: Lessons learnt from the introduction of IWRM and river basin management in Mongolia. *Environmental Science and Policy* 75: 28-37. https://doi.org/10.1016/j.envsci.2017.05.009

Hussey, K. and Pittock, J. 2012. The energy-water nexus: Managing the links between energy and water for sustainable future. *Ecology and Society* 17(1): 31-39. https://doi.org/10.5751/es-04641-170131

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the IPCC by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976. https://doi.org/10.2134/jeq2008.0015br

International Energy Agency (IEA). 2016. Energy, climate change and environment: A report by IEA. Online: http://www.iea.org/publications/freepublications/publication/ECCE2016.pdf (Accessed: 23 May 2017). https://doi.org/10.1787/9789264239272-en

Jagerskog, A., Clausen, T. J., Holmgren, T. and Lexen, K. 2014. Energy and Water: The vital link for a sustainable future: Report for the world water week. Report no 33. Stockholm, Sweden, 31st August – 5th September 2014.

Karar, E. 2008. Integrated water resource management (IWRM): Lessons from implementation in developing countries: Foreword to the IWRM conference special edition. *Water SA* 34(6): 661-664. https://doi.org/10.4314/wsa.v34i6.183666

Kubiszewski, I. and Cleveland, C. 2012. United Nations Conference on Environment and Development, Rio de Janeiro, Brazil. Online: http://editors.eol.org/eoearth/wiki/United_Nations_Conference_on_Environment_and_Development_(UNCED),_Rio_de_Janeiro,_Brazil (Accessed: 26 March 2018). https://doi.org/10.1007/springerreference_29770

Leendertse, K., Mitchell, S. A. M. and Harlin, J. 2008. IWRM and the environment: A view on their interaction and examples where IWRM led to better environmental management in developing countries. *Water SA* 34(6): 691-698. https://doi.org/10.4314/wsa.v34i6.183671

Mabhaudhi, T., Mpandeli, S., Madhlopa, A., Modi, A. T., Backeberg, G. and Nhamo, L. 2016. Southern Africa's water-energy nexus: Towards regional integration and development. *Water* 8(6): 1-21. https://doi.org/10.3390/w8060235

Madhlopa, A., Pegram, G., Sauka, S., Sparks, D., Keen, S. and Moorlach, M. 2016. The water-energy nexus in the context of climate change: Investigating trade-offs between water use efficiency and renewable energy options for South Africa. Report to the Water Research Commission. WRC Report No 2239/1/15. March 2016. https://doi.org/10.1016/j.rser.2015.03.051

Masters, L. 2009. Climate change, energy and South Africa's foreign policy: The road to Copenhagen. South African Institute of International Affairs, Occasional Paper No. 47.

Mathetsa, S. 2016. Assessing water quality status by means of the Driver-Pressure-State-Impact-Response (DPSIR) model around Mapungubwe National Park, Limpopo Province, South Africa. MSc Thesis. University of South Africa, South Africa.

Mukheibir, P. 2008. Water resources management strategies for adaptation to climate-induced impacts in South Africa. *Water Resources Management* 22: 1259–1276. https://doi.org/10.1007/s11269-007-9224-6

Muller, M. 2015. The 'nexus' as a step back towards a more coherent water resource management paradigm. *Water Alternatives* 8(1): 675-694.

Natural Resource Defense Council (NRDC). 2010. Climate change and water resource management, adaptation strategies for protecting people and the environment. Available online: https://www.nrdc.org/sites/default/files/waterandclimate.pdf (Accessed: 05 May 2017).

Nesheim, I., McNeill, D., Joy, K. S., Manasi, S., Nhung, D. T. K., Portela, M. M. and Paranjape, S. 2010. The challenges and status of IWRM in four river basins in Europe and Asia. *Irrigation and Drainage Systems* 24(3-4): 205-221. https://doi.org/10.1007/s10795-010-9103-9

Nhamo, L., Ndlela, B., Nhemachena, C., Mabhaudhi, T., Mpandeli, S. and Matchaya, G. 2018. The water-energy-food nexus: Climate risks and opportunities in Southern Africa. *Water* 10 (5): 567-584. https://doi.org/10.3390/w10050567

Nkhonjera, K. G. 2017. Understanding the impact of climate change on the dwindling water resources of South Africa, focusing mainly on Olifants River basin: A review. *Environmental Science and Policy* 71: 19–29. https://doi.org/10.1016/j.envsci.2017.02.004

Omer, M. A. 2008. Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews* 12: 2265-2300. https://doi.org/10.1016/j.rser.2007.05.001

Pahl-wostl, C., Bhaduri, A., and Bruns, A. 2018. The nexus of water, energy and food-an environmental governance perspective. *Environmental Science and Policy*. https://doi.org/10.1016/j.envsci.2018.06.021

Platonova, I. and Leone, L. 2012. The energy-water nexus in the context of climate change in developing countries: Experiences from Latin America, East and Southern Africa. Synthesis Report for Climate Change and Water Program, Ottawa, Canada, 7 November 2012.

Pollard, S. and Du Toit, D. 2008. Integrated water resource management in complex systems: How the catchment management strategies seek to achieve sustainability and equity in water resources in South Africa. *Water SA* 34(6): 671-680. https://doi.org/10.4314/wsa.v34i6.183668

Prasad, G., Boulle, M., Boyd, A., Rahlao, S., Wlokas, H. and Yaholnitsky, I. 2012. Energy, water and climate change in Southern Africa: What are the issues that need further investment and research? Energy Research Centre, University of Cape Town, Cape Town, South Africa. https://doi.org/10.17159/sajs.2016/20160202

Rasul, G. and Sharma, B. 2016. The nexus approach to water-energy-food security: An option for adaptation to climate change. *Climate Policy* 16(6): 682-702. https://doi.org/10.1080/14693062.2015.1029865

Reynolds, J. and Cranston, G. 2014. Nexus thinking: Can it slow the great acceleration?. Economic and Social Research Council. Available online: https://www.cisl.cam.ac.uk/resources/latest-publications/nexus-thinking-can-it-slow-the-great-acceleration. (Accessed: 11 March 2019)

Scott, A. C., Pierce, A. S., Pasqualetti, M. J., Jones, L. A., Montz, B. E. and Hoover, H. J. 2011. Policy and institutional dimensions of the water-energy nexus. *Energy Policy* 39: 6622-6630. https://doi.org/10.1016/j.enpol.2011.08.013

Siddiqi, A. and Anadon, D. L. 2011. The water-energy nexus in Middle East and North Africa. *Energy Policy* 39: 4529-4540. https://doi.org/10.1016/j.enpol.2011.04.023

Simpson, G. B. and Jewitt, G. P. W. 2019. The development of the water-energy-food nexus as a framework for achieving resource security: A review. *Frontiers of Environmental Science*. 7:8. https://doi.org/10.3389/fenvs.2019.00008

Sparks, D., Madhlopa, A., Keen, S., Moorlach, M., Dane, A., Krog, P. and Dlamini, T. 2014. Renewable energy choices and their water requirements in South Africa. *Journal of Energy in Southern Africa* 25(4): 80-92. https://doi.org/10.17159/2413-3051/2014/v25i4a2241

Stein, C., Pahl-wostl, C. and Barron, J. 2018. Towards a relational understanding of the water-energy-food nexus: analysis of embeddedness and governance in the Upper Blue Nile region of Ethiopia. *Environmental Science and Policy*. https://doi.org/10.1016/j.envsci.2018.01.018.

Taylor-Wood, E. and Fuller, D. 2017. 'Nexus thinking' for a secure and sustainable future. Available online: http://www.entura.com.au/nexus-thinking-secure-sustainable-future (Accessed: 01 March 2019).

Trollip, H. and Boulle, M. 2017. Challenges associated with implementing climate change mitigation policy in South Africa. Energy Research Centre, University of Cape Town, Cape Town, South Africa. https://doi.org/10.15641/ghi.v2i1.728

United Nations. 1972. Report of the United Nations conference on the human environment. Stockholm, 5-16 June

1972, Document No. A/CONF.48/14/Rev.1. *United Nations Publications*, New York, USA. https://doi.org/10.18356/7f7f8caf-en

United Nations. 1992. United Nations framework convention on climate change. online:http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf Report No. FCCC/INFORMAL/84 (Accessed: 15 March 2017).

United Nations. 2015. Sustainable Development Goals Post-2015: Transforming our world-the 2030 agenda for sustainable development. In: Resolution adopted by the General Assembly on 25 September 2015. Available online. https://sustainabledevelopment.un.org/focussdgs.html (Accessed: 28 March 2018).

United States Department of Energy (US DoE). 2014. The water-energy nexus: Challenges and opportunities. Report for the US DoE, June 2014.

Wakeford, J. J. 2017. The water–energy–food nexus in a climate-vulnerable, frontier economy: The case of Kenya. Report Prepared for the United Kingdom department for international development by the Sustainability Institute South Africa, March 2017.

Walmsley, J., Carden, M., Revenga, C., Sagona, F. and Smith, M. 2001. Indicators of sustainable development for catchment management in South Africa - Review of indicators from around the world. *Water SA* 27: 539-550. https://doi.org/10.4314/wsa.v27i4.4968

Winkler, H., Davidson, O., Kenny, A., Prasad, G., Sparks, D., Howells, M. and Alfstad, T. 2006. Energy policies for sustainable development in South Africa, options for the future. Energy Research Centre, University of Cape Town, Cape Town. https://doi.org/10.15641/ghi.v2i1.728

World Bank. 2017. Modeling the water-energy nexus: How do water constraints affect energy planning in South Africa?. World Bank, Washington DC. https://doi.org/10.1596/26255

Yillia, P. 2019. Personal communication, 15th May 2019. Dr. Paul Yillia, International Institute for Applied Systems Analysis, Laxenburg, Lower Austria, Austria.

Ziervogel, G., New, M., Van Gardener, E. A., Midgley, G., Taylor, A., Hamann, R., Stuart-Hill, S., Myers, J. and Warburton, M. 2014. Climate change impacts and adaptation in South Africa. *WIREs Climate Change* 5: 605-620. https://doi.org/10.1002/wcc.295.