Assessing the State of the Water-Energy-Food (WEF) Nexus in South Africa

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

The water-energy-food (WEF) nexus is gaining recognition internationally as an intersectoral approach to resource management and sustainable development. The Water Research Commission (WRC) of South Africa has identified the WEF nexus as one of its focus "lighthouse" areas of research. This project was part of the WRC's goal to promote the WEF nexus in South Africa. The general aim of the study was to conduct a review of available information and knowledge about the Water-Energy-Food nexus in South Africa. Specifically, to conduct a state-of-the-art literature review on past, present and ongoing work on the WEF nexus focusing on current status, potential, challenges and opportunities for intersectoral WEF Nexus planning. In addition, to propose a framework for linking the WEF Nexus to the Sustainable Development Goals (SDGs), paying emphasis on SDG 2, 6 and 7. Lastly, this would culminate in developing a draft research agenda to guide future research and develop on the WEF nexus for South Africa.

Much of the WEF nexus information that has been produced has a regional SADC focus. South Africa, however, has many opportunities to implement WEF nexus thinking in resource management. Solar power generation, water reuse and recycling, and precision agriculture are examples of opportunities that could contribute to intersectoral optimisation. For South Africa it is imperative that the WEF nexus approach be closely aligned with the SDGs, particularly to SDGs 2 (zero hunger), 6 (clean water and sanitation) and 7 (affordable and clean energy).

A diverse set of challenges hinder the effective implementation of the WEF nexus in South Africa. As a developing country, South Africa's primary focus is on alleviating poverty, inequality, and corruption while attempting to increase economic growth. Secondly, resource management and policy development are generally sector-specific with little acknowledgement of adjacent sectors. Thirdly, data related to the three sectors, and especially their interactions, are frequently unavailable, inaccessible or unusable due to scale, unit or temporal differences. Further, WEF nexus implementation will be subject to its inclusion in national policies and standards, implying the integration of the water, energy and agricultural departments.

A systematic analysis of existing WEF nexus frameworks in academic and grey literature resulted in the development of a South African framework that considers the three sectors as well as technological innovations, human-wellbeing, SDGs and different drivers of the WEF nexus. It is proposed that this framework be utilised as a point of departure for future research related to the WEF nexus in South Africa. To this end a research agenda for the WEF nexus in South Africa is proposed in this document.

Future research on the WEF nexus should focus on (i) developing an integrated model, metrics and indices to assess the WEF nexus in South Africa, and creating a WEF nexus database, (ii) translation of existing knowledge to inform policies for integrated sustainable resource management among the WEF sectors, (iii) participatory research aimed at demonstrating the applicability of the WEF nexus at the local level, especially among the poor, and generating cases that demonstrate how the WEF nexus could assist in achieving SDGs 2, 6 and 7. South Africa is well positioned to achieve these goals as there are large data sets already in existence. The development of a WEF nexus model, metrics and indices would help to unlock the value of such existing data and also guide the generation of new data sets.

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ABBREVIATIONS AND ACRONYMS

ACDI	African Climate & Development Initiative	An interdisciplinary research and training institute that brings together academics, NGOs, business, civil society and government.
AEZ	Agro-ecological zone	Geographic zones of similar climatic and edaphic characteristics and agricultural potential.
ANEMI	An ancient Greek term for the four winds, heralds of the four seasons	A dynamic model for considering the interconnections between water, energy and food in a complex society-biosphere-climate system.
ARC	Agricultural Research Council	A South African research council that conducts research within the agricultural sector.
BFAP	Bureau for Food and Agricultural Policy	A non-profit organisation that informs and supports decision-making by stakeholders in the agro-food, fibre and beverage sectors of Africa.
CGIAR	Consultative Group for International Agricultural Research	A global partnership that unites organisations engaged in research for a food-secured future.
CHEC	Cape Higher Education Consortium	An association whose members are the four universities in the Western Cape province of South Africa (Cape Peninsula University of Technology, Stellenbosch University, University of Cape Town, and University of the Western Cape).
CLEWS	Climate Land-use Energy and Water Strategies	A modelling framework that analyses interlinkages between sectors to determine the effect that one sector might have on the others and identifies counter-intuitive responses in these integrated systems.
CMA	Catchment Management Agencies	Agencies responsible for managing water resources at catchment management level in cooperation with local stakeholders.
CSAG	Climate Systems Analysis Group	A research group within Africa that seeks to apply core research to meet the knowledge needs of responding to climate variability and change.
CSIR	Council for Scientific and Industrial Research	A scientific research and development organisation based in South Africa.
CSP	Concentrated Solar Power	Solar thermal energy is generated using mirrors or lenses that concentrate sunlight onto a small area.
CWRR	Centre for Water Resource Research	A water resource research group from UKZN.

DAFF	Department of Agriculture, Forestry and Fisheries	South Africa's National department that oversees the agricultural, forestry and fisheries sectors.
DAFNE	Decision Analytic Framework to explore the WEF nexus	An integrated and adaptive water resources planning and management approach that addresses the water-energy-food nexus from a novel participatory and multidisciplinary perspective.
DEA	Data Envelopment Analysis Model	A method in operations research and economics for the estimation of production frontiers. It is used to empirically measure productive efficiency of decision making units.
DEA	Department of Environmental Affairs	South Africa's national department that regulates environmental management, including climate change.
DES	Distributed Energy Systems	Local conversion of renewable resources (solar radiation, wind, biomass, and small hydropower) into thermal energy or electricity.
DoE	Department of Energy	South Africa' national department that regulates the energy sector.
DMR	Department of Mineral Resources	South Africa' national department that regulates the mining sector.
DRC	Democratic Republic of the Congo	Formerly referred to as Zaire, is a central African State, which also forms part of the SADC regional economic block.
DWS	Department of Water and Sanitation	South Africa' national department that regulates the water sector.
ERC	Energy Research Centre	A merger of the Energy Research Institute and the Energy Development Research Centre at the University of Cape Town.
FAO	Food and Agriculture Organisation	A UN agency that works internationally to reduce hunger by helping developing countries modernise and improve agriculture, forestry and fisheries practices.
GDP	Gross domestic product	A monetary measure of the market value of all final goods and services produced in a period.
GEO	Group on Earth Observation	A global network of institutions, businesses and experts that creates innovative solutions to global challenges that transcend national and disciplinary boundaries.

GGGI	Global Green Growth Institute	A treaty-based international, inter-governmental organisation that supports and promotes strong, inclusive and sustainable economic growth in developing countries.
GLOBIOM	Global Biosphere Management model	A model used to analyse the competition for land use between agriculture, forestry, and bioenergy.
GWP	Global Water Partnership	An international network created to foster an integrated approach to water resources management.
GWP-SA	Global Water Partnership – Southern Africa	An organisation that adopts an integrated approach to water resources management within the SADC.
IRENA	International Renewable Energy Agency	An intergovernmental organisation that promotes the adoption and sustainable use of renewable energy.
IRP	Integrated Resource Plan	A plan that directs the expansion of electricity supply to meet the forecasted demand with minimum cost to the country.
IWRM	Integrated water resource management	Promotes the coordinated development and management of water, land and related resources to maximise economic and social welfare without compromising the sustainability of vital ecosystems and the environment.
IWMI-SA	International Water Management Institute-Southern Africa	A non-profit, scientific research organisation that focuses on the sustainable use of water and land resources in developing countries.
LEAP	Long-range Energy Alternatives Planning	A software tool for energy policy analysis and climate change mitigation assessment.
LHWP	Lesotho Highlands Water Project	A water supply project developed in partnership between the governments of Lesotho and South Africa, with a hydropower component. It is Africa's largest water transfer scheme.
LIMCOM	Limpopo Watercourse Commission	A technical advisor to the contracting parties on matters related to the development, utilisation and conservation of the water resources in Limpopo.
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change	A model that allows users to investigate future climate change and its uncertainties at global-mean and regional levels.
MDGs	Millennium Development Goals	Eight goals with measurable targets and clear deadlines for improving the lives of the world's poorest people and was the predecessor of SDGs.
MESSAGE	Model for Energy Supply Systems and their General Environmental impact	A dynamic linear programming model which simulates potential future energy scenarios and can be combined with other models to obtain a more inclusive set of data.

MuSIASEM	Multi-Scale Integrated Assessment of Society and Ecosystem Metabolism	A tool to characterise patterns of an existing socio-economic system or checking self-consistency and implications of a scenario.
NDP	National Development Plan	An action plan for securing the future of South Africans developed by the National Planning Commission.
NGOs	Non-Governmental Organisations	A non-profit organisation that works independently of governmental agencies to address social, political or environmental issues.
NXI	Nexus City Index	Measures the prosperity and sustainability of the WEF nexus.
PRIMA	Platform for Regional Integrated Modelling and Analysis	Incorporates models of climate, socioeconomics, hydrology, agriculture, buildings, electricity, and other sectors to simulate the complex interactions at the climate-energy-water-land nexus at decision-relevant scales.
QEERI	Qatar Environment and Energy Research Institute	An institute that researches energy and environmental issues that may affect the rapidly-developing country of Qatar.
RISDP	Regional Indicative Strategic Development Plan	A development and implementation framework guiding the Regional Integration agenda of the SADC over a period of fifteen years (2005-2020).
RSAP	Regional Strategic Action Plan	A framework to achieve the sustainable development of water resources through the development of water infrastructures based on water governance and water management.
RVAC	Regional Vulnerability Assessment Committee	Established by the SADC, this committee drives improvements in vulnerability analysis and food security at both regional and country level.
REIPPA	Renewable Energy Independent Power Purchase Agreements	An entity, which is not part of the public, which owns renewable energy facilities that generate electric power for sale to end users.
SADC	Southern African Development Community	A Regional Economic Community comprising of fifteen Member States, committed to Regional Integration and poverty eradication within Southern Africa through economic development and ensuring peace and security.
SAEES	School of Agricultural, Earth and Environmental Sciences	One of five Schools housed within the College of Agriculture, Engineering and Science at UKZN.
SALGA	South African Local Government Association	The constitutionally mandated organisation responsible for local government oversight.
SANEDI	South African National Energy Development Institute	Promotes the innovation of clean energy solutions and rational energy use in South Africa.
SASOL	South African Synthetic Oil Limited	An integrated energy and chemical company in South Africa.

SATIM-W	South African TIMES Water-Energy model	A tool that offers insight into the trade-offs between water and energy systems as part of cost-effective sustainable planning.
SDGs	Sustainable Development Goals	A set of seventeen goals presenting a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity.
SEACMEQ	Southern and Eastern Africa Consortium for Monitoring Educational Quality	An international non-profit developmental organisation that shares experiences and expertise in developing the capacities of education planners to apply scientific methods to monitor and evaluate the conditions of schooling and the quality of education.
SME	Small and medium-sized enterprises	Small and medium-sized enterprises or businesses are businesses whose personnel numbers fall below specified limits.
UCT	University of Cape Town	A public teaching and research university located in Cape Town, in the Western Cape province of South Africa.
UFH	University of Fort Hare	A public teaching and research university located in Alice, in the Eastern Cape province of South Africa.
UFS	University of the Free State	A public teaching and research university located in Bloemfontein, in the Free State province of South Africa.
UKZN	University of KwaZulu-Natal	A public teaching and research university located in Durban & Pietermaritzburg in the KwaZulu-Natal province of South Africa.
UN	United Nations	An intergovernmental organisation that promotes international cooperation to create and maintain international order.
UN DESA	United Nations Department of Economic and Social Affairs	Assists countries in setting agendas and decision-making with reference to their economic, social and environmental challenges.
UNEP	United Nations Environment Programme	An agency of United Nations that coordinates its environmental activities and assists developing countries in implementing environmentally-sound policies and practices.
UOG	Unconventional oil and gas	Oil and gas extracted from a wider variety of sources as opposed to conventional oil and gas, considered to be new and different within a given area.
WASH	Water, Sanitation and Hygiene	A project that focuses on reducing the spread of preventable waterborne diseases in Africa.
WEAP	Water Evaluation and Planning	A software tool that takes an integrated approach to water resources planning.
WEF	World Economic Forum	A non-profit international organisation committed to improving the state of the world by engaging business, political, academic and other leaders of society to shape global, regional and industry agendas.

WEF Nexus	Water-energy-food nexus	An approach to sustainable development that centres on three sectors — water security, energy security and food security — that are inextricably linked, and actions in one area often has impacts in one or both of the others.
WWF	World Wide Fund for Nature	An international non-governmental organisation founded in 1961, working in the field of the wilderness preservation, and the reduction of human impacts on the environment.
WWF-SA	World Wide Fund for Nature – South Africa	A non-governmental organisation working in the field of wildlife preservation and reduction of human impacts on the environment, based in South Africa.
ZAMCOM	Zambezi Watercourse Commission	A water management organisation established by the SADC whose territory contains the Zambezi river basin.
ZLD	Zero Liquid Discharge	A treatment system that uses advanced technological water treatment processes to limit liquid waste.

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INTRODUCTION

Background

Sustainable resource management has become a major world-wide governance concern over the last three decades. The challenge is growing as the demand for natural resources increases exponentially with population and economic growth. The current nature of human resource consumption is, however, disproportionate with the wealthiest continents (North America and Europe) consuming on average ten times more resources than poor continents (Africa, West Asia, etc.) (UNEP, 2016). International trade of natural resources contributes significantly to the gross domestic product (GDP) of many developing countries, but is often referred to as a 'curse', where countries with an abundance of natural resources are also those suffering from poverty, inequality, conflict and insecurity (Ross, 1999). An integrated approach to managing natural resources is required if the Sustainable Development Goals (SDGs) are to be realised by 2030.

Since 2011, the Water-Energy-Food (WEF) nexus has been investigated by many actors, each approaching their analyses with their niche or sector in mind, be they political, social, or scientific perspectives. The WEF nexus is broadly defined as an approach that considers the interactions, synergies and trade-offs of water, energy and food when undertaking the management of these resources. Water, energy and food securities are inextricably linked, with usage within one sector influencing the use and availability in the adjacent sectors. Unlike Integrated Water Resource Management (IWRM), which is water-centric in nature, the goal of the WEF nexus is to approach resource management more holistically by utilising a multi-centric philosophy. Each resource sector within this nexus has an equal weighting. The WEF nexus presents an opportunity for policymakers, researchers and development agencies to integrate the sectors to optimise the use of the resource base, maximise synergies and minimise trade-offs and conflicts.

The WEF nexus is closely aligned to the SDGs, particularly SDGs 2 (zero hunger), 6 (clean water and sanitation) and 7 (affordable and clean energy). Originally, SDGs (a follow-on from the MDGs) were established as a response to world poverty, inequality, and insecurity, but they have developed into drivers of the management of resources. Developing countries, like South Africa, are likely to benefit greatly from the integrated resource management approach that the WEF nexus provides, particularly those experiencing significant trade-offs between water, energy and food.

South Africa is a water-scarce country with approximately 13% arable land, much of which coincides with regions that have a high concentration of mineral resources, e.g. coal. About 30% of South Africa's crops are produced on irrigated land, accounting for approximately 75% of the total national agricultural water use (Ololade et al., 2017). From 1985 to 2008, South Africa was a net food exporter. However, in recent years the situation has changed due to a reduction in agricultural yields and an increased population (Ololade et al., 2017). The country is heavily reliant on non-renewable energy resources. As a result of the projected growth in national populations, together with economic development, several countries within the Southern African Development Community (SADC) will be water-stressed by 2040, with South Africa experiencing a high ratio of water withdrawals to supply (World Resources Institute, 2015). Figure 1 presents a map indicating the levels of projected water stress in the world by 2040. The high 'water stress' values in South Africa, Lesotho, Namibia and Zimbabwe are evident in this figure.

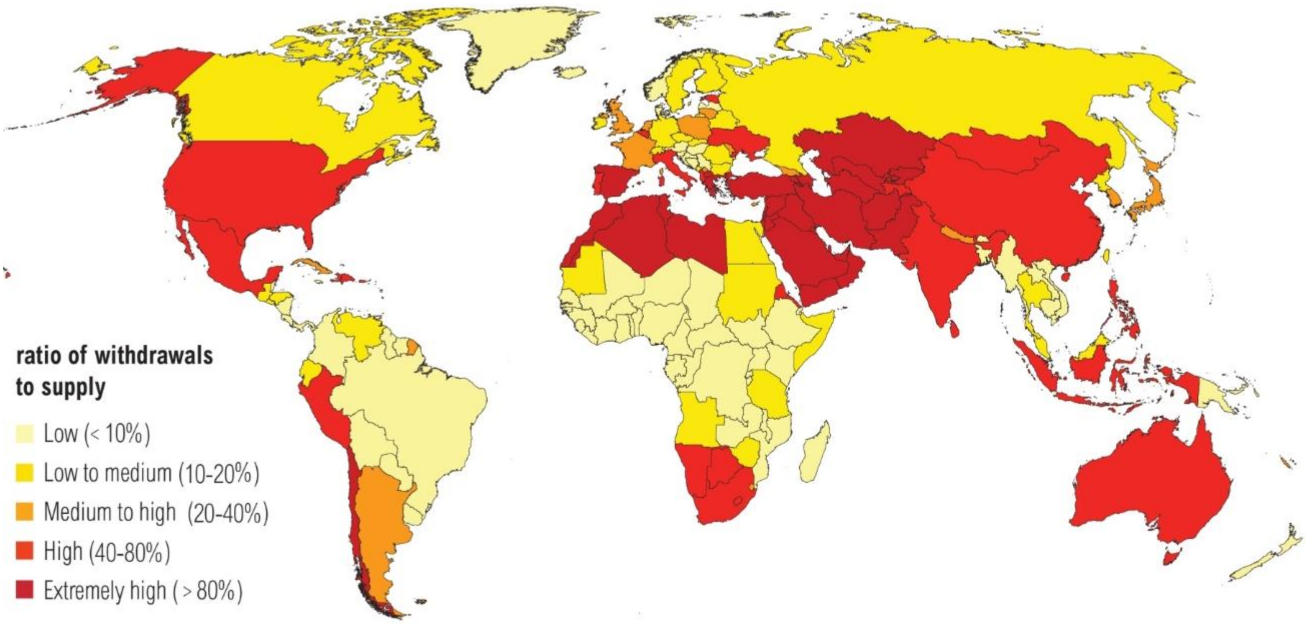

Figure 1: Projected global water stress by 2040 (World Resources Institute, 2015).

The world's major urban areas tend to develop near freshwater sources, yet South Africa's largest metropolitan area, Johannesburg and surrounds, developed inland because of employment opportunities associated with gold mining in the area. The water shortages that South Africa faces in this region are directly related to this city's location relative to the available national water resources.

Inter-basin water transfers (both national and international) are essential for addressing South Africa's water security, and efforts are regularly made to secure access to water resources beyond its national borders. Currently, South Africa is seeking regional solutions to water security challenges by creating joint committees with neighbouring countries such as Zimbabwe, Lesotho and Botswana (The World Bank, 2016). The water scarcity situation in South Africa emphasises the importance of maintaining the existing infrastructure used to transport, transfer and treat water. Together with these international considerations, South Africa will be building and enlarging numerous dams during the next decade to service its increasing population with water and sanitation needs (DWS, 2015).

Water and energy resources in South Africa are closely linked, and ultimately determine the availability and abundance of the other. Approximately 86% of the country's electricity is generated in coal-fired power stations (Carter and Gulati, 2014). Generally, coal mining activities in the Mpumalanga Province occur within areas where high potential arable land is also located, as shown in Figure 2. The process of energy generation by means of coal requires substantial amounts of water, while also impacting on water quality (Bobbins, 2015). Both agricultural and mining activities therefore have significant impacts on the local water quality and quantity in Mpumalanga, while competing for land (Ololade et al., 2017). The Olifants River catchment in South Africa has been impacted by mining activities to such an extent that the water has been categorised as being unsuitable for human or animal consumption. The water, as a result, requires treatment which is generally highly energy-intensive, and therefore costly (IRENA, 2015).

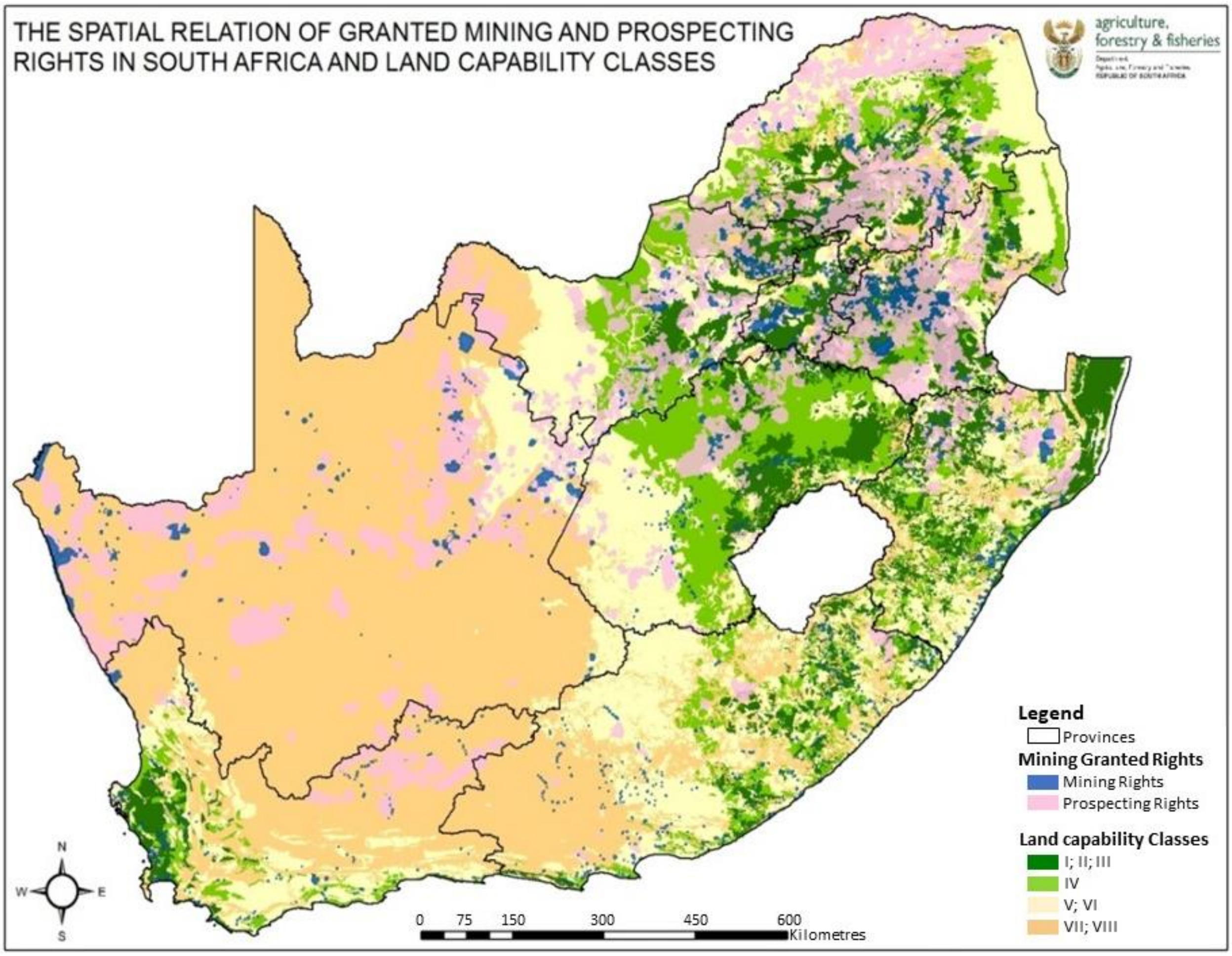

Figure 2: Map showing the overlap of arable land capability and mining rights in South Africa (DAFF, 2015).

The mitigation and remediation of acid mine drainage flowing towards inland water bodies, e.g. the Loskop dam, has been an ongoing challenge for mines in South Africa (Ololade et al., 2017). This has had a negative impact on the wellbeing of the environment, yet fossil-fuel based energy generation will continue to dominate the sector for the coming decades.

To deal with South Africa's mounting energy needs, Eskom is in the process of building two new large coal-fired power stations, namely Medupi and Kusile (Goga and Pegram, 2014). The design of Medupi and Kusile accommodates the limited water availability in their respective areas by utilising dry-cooling systems. The power stations will operate under Eskom's Zero Liquid Discharge (ZLD) policy, which states that water discharged into receiving water bodies should be of an equal quality, or better, than before it was utilised (Inglesi-Lotz and Blignaut, 2012).

The SDGs resonate with the South African constitution, particularly when reference is made to the livelihoods of people. Historically, policies have mostly had a sectoral approach, which has led to key resource constraints and policy considerations being regarded in isolation (Leck et al., 2015). The WEF nexus provides the opportunity to move beyond the current sectoral approach to policy-making, highlighting the interlinkages between the sectors and the need to implement system thinking to achieve the SDGs.

Scope and Purpose

Water, energy and food are three of the key pillars upon which humanity exists and develops. But these pillars are not independent. Rather, a multitude of connections and trade-offs and synergies exist between them. For instance, water is utilised in agricultural irrigation and food processing. Water is also essential for energy generation, be it directly in the case of hydropower or indirectly in coal mining. Energy is utilised in the pumping and distribution of water and for the mechanisation of various agricultural activities. The nexus approach to resource sector management seeks to understand the linkages, dependencies, and trade-offs associated with the core elements within the nexus under assessment.

The basis of the nexus approach is an attempt to balance different uses of ecosystem resources (energy, water, land, soil and socio-economic factors) (Kurian and Ardakanian, 2015). There are clear interactions between water, energy and food (WEF) that may result in synergies or trade-offs between different sectors or interest groups (Granit et al., 2013). Thus, the nexus approach allows for a better understanding of the dynamic inter-relationships between water, food and energy. WEF nexus treats water, energy, and food equally and recognizes that the three sectors are interdependent. Any approach that excludes one component of the WEF while considering the other two might fail to sustain the nexus equilibrium (Bazilian et al., 2011). By treating the three sectors equally it establishes that no sector takes precedence over the other two and ensures consideration of other sectors when a decision on one sector is being made. This encourages dialogue among different sectors and collective efforts to problem solving and decision making. In terms of policy and planning, this links to the concept integrated resource planning, which has been a hallmark of several key South African policies.

The regulatory custodians of water, energy and agriculture often reside in separate departments. With a lack of coordination between them, these departments can (and do) promote conflicting programmes that inadvertently threaten the security associated with an adjacent sector. One of the reasons for this lack of coordination is that a general understanding of the nexus dynamics is limited. For example, the expansion of coal mining in South Africa due to energy demand, has come into conflict with agriculture and water resource managers in Mpumalanga and Limpopo Provinces. Similarly, the National Development Plan's target of increasing area under irrigation by 500 000 ha risks placing a further strain on South Africa's already scarce water resources, as well energy that will be needed for pumping the water. While most of these initiatives are designed with good intention, a lack of WEF nexus considerations threatens their implementation and sustainability. Thus, the WEF nexus approach is also an approach for sustainable economic development.

The Water Research Commission (WRC) has been championing the WEF nexus approach since it first came to light in Davos in 2011. Thereafter, the WRC initiated its WEF Nexus Lighthouse with a goal to start championing water, energy and food planning and development for South Africa in an integrated and sustainable manner. The current Terms of Reference are part of the WRC's current strategy to promote the WEF nexus within South Africa, and the region. The motivation for the development of a state-of-the-art literature review detailing current and available knowledge on the WEF nexus in South Africa is to provide a comprehensive assessment of this body of research, such that it can be accessed by all researchers in South Africa and applied to policy decisions. To facilitate this integration, this assessment will include a review of existing water, energy, food polices and strategies at a national level with a view to identifying gaps and opportunities for alignment based on the WEF nexus.

The proposed literature review will also highlight opportunities for linking the WEF nexus to the Sustainable Development Goals (SDGs), which represents the focus of the United Nation's efforts. The WEF nexus presents a framework for directly achieving some of the SDGs, such as Goals 2, 6 and 7, with indirect potential to achieve SDGs 1, 8 and 9 through job creation and innovations linked to WEF nexus sensitive planning.

Overall objective

The general aim of the project is to conduct a review of available information and knowledge about the Water-Energy-Food nexus in South Africa. Secondly, the project also aims to conduct a state-of-the-art literature review on past, present and ongoing work on the Water-Energy-Food nexus focusing on current status, potential, challenges and opportunities for intersectoral WEF Nexus planning. The review will pay attention to both technical and policy issues. Lastly, the project will develop a programme/framework for linking the WEF Nexus to the Sustainable Development Goals (SDGs), paying emphasis on SDG 2, 6 and 7.

Specific objectives

i. Review of current knowledge on water-energy-food nexus in South Africa, including the review of current water, energy, food polices and strategies at national level.

ii. Identify policy and research gaps and make recommendations for practical application of the water-energy-food nexus in bringing about policy alignment and coherence. Develop a draft framework for implementing the water-energy-food nexus, linked to the SDGs, for the Water Research Commission and South Africa.

iii. Develop mechanisms for identifying local research champions for the water-energy-food nexus and development of a database of professionals working on the water-energy-food nexus.

iv. To develop a national guideline and research agenda for prioritising water-energy-food nexus research, development and innovation for South Africa. The agenda should align with international initiatives to allow South Africa to tap into global funding for water, energy and food nexus.

v. To a limited extent, propose indices and/or metrics as well as models that could be used to evaluate the water-energy-food nexus.

CHAPTER 1

LITERATURE REVIEW OF THE WEF NEXUS IN SOUTH AFRICA

1.1 Brief History of The Water-Energy-Food Nexus

During the late 2000s and early 2010s, the WEF nexus emerged as an approach to sustainably manage these three resource sectors, following the convergence of ideas from various political events, academic research and reports, as well as policy papers. The approach was consolidated by the *2030 Water Resources Group* of The World Bank in 2008, which consisted of several role players predominantly associated with food and beverage industries, such as the Coca-Cola Company, SABMiller, Nestlé and New Holland Agriculture (Leese and Meisch, 2015). The group was originally formed when group members responded to the political and economic threat of water scarcity and eventually partnered with the Global Green Growth Institute (GGGI), the World Economic Forum (WEF), the World Wild Fund for Nature (WWF) and the Global Water Partnership (GWP). Following the conceptualisation of the WEF nexus, several conferences have been held to develop and promote the nexus approach. A prominent catalyst for the WEF nexus was the Bonn conference of 2011, which significantly increased the profile of the framework internationally (Leck et al., 2015). The Bonn conference focused on the need to integrate efforts to secure water, energy and food security, and highlighted current and future issues related to sustainable development. The conference further aimed to better understand the interlinkages between climate, water, food and energy through mitigating trade-offs, increasing efficiency, improving governance and building synergies across the sectors (Chirisa and Bandauko, 2015; Leese and Meisch, 2015).

The SADC region has been actively involved in WEF nexus research development. In 2013, the SADC and GWP-SA explored the WEF nexus at the *6th Multi-stakeholder Water Dialogue* in Lusaka, Zambia, where the interlinkages of the WEF nexus were addressed. Three years later, the SADC *Energy and Water Joint Ministerial Workshop* helped create WEF nexus awareness and context in the SADC region. The workshop proposed various steps to inform regional stakeholders on key overarching issues concerning the nexus, which included identifying relevant stakeholders and champions, conducting workshops at different levels (regional, national, sectoral and cross-sectoral) and identifying significant data gaps (The World Bank 2016). In the same year, a technical workshop was held in Pietermaritzburg investigating the WEF nexus and its linkages with the goal of the achieving the SDGs. This was the fourth and final workshop held in connection with the Future Earth WEF nexus initiative. In 2017, the SADC hosted a two-day meeting in Johannesburg, supported by the *EU WEF Nexus Dialogue Program*, promoting the efficient use of resources relating to water, energy and land planning. The meeting highlighted the role of stakeholders and governments in the decision-making of WEF nexus resources and the management thereof. In short, the WEF nexus was conceived as an approach to sustainable manage resources by understanding the interlinkages among water, energy and food.

The purpose of this literature review was to provide detailed documentation relating to the current and available knowledge on the WEF nexus in South Africa. This included a review of existing water, energy, and food polices and strategies at a national level, with a view to identifying gaps and opportunities for alignment based on the WEF nexus. The review also sought to highlight opportunities for linking the WEF nexus to the SDGs and to investigate the use of models and/or indices to evaluate the nexus in focus. Lastly, we reviewed WEF nexus issues in need of further research, so as to enhance better understanding and operationalising of the nexus under South African conditions.

The selection of literature for this review was conducted based on the Collaboration for Environmental Evidence (2013) guidelines for systematic reviews. The databases were selected based on their relevance and credibility. Meta data was created based on the search results for the various databases, and grey literature was obtained from relevant sources such as the Food and Agriculture Organisation (FAO), World Wide Fund for Nature – South Africa (WWF-SA) and Bureau for Food and Agricultural Policy (BFAP) as well as literature identified by experts in the field.

The meta data associated with the systematic selection of literature for this review is contained in Appendix A of this document.

1.2 Current Status of The WEF Nexus in South Africa

1.2.1 Regional

There have been various workshops, dialogues and consultations on the importance of the WEF nexus at a regional level, as noted in the previous section. The SADC Water Division, the SADC River Basin Organisation and regional implementation partners such as Global Water Partnership-Southern Africa (GWP-SA) have been engaging in discussions concerning the broader socio-economic and political environment affecting the WEF nexus (World Water Forum, 2018).

The SADC is the main institution that focuses on regional integration and currently has 26 protocols in place, including those on shared water resources and energy (The World Bank, 2016). The SADC countries need to improve agricultural production and industrial development, which in turn is interlinked with water and energy supply. This may negatively impact upon the achievement of the SDGs and regional economic targets (Mabhaudhi et al., 2016). The WEF nexus approach is relevant to the SADC region, since energy infrastructure and water resources are shared between countries in the region.

The SADC region receives support through the SADC-EU Nexus Dialogue Project, which has an operational period of 2016 to 2019, and has prioritised the development of the WEF nexus by implementing a Regional Strategic Action Plan (RSAP) (World Water Forum, 2018). The current RSAP IV (2016-2020) consists of eight programmes, one of which is centred on the WEF security nexus (SADC, 2016).

The RSAP IV deals with facilitating both political and technical discourse on the WEF nexus, as well as establishing a nexus governance structure in SADC for investments. The SADC views the nexus from two main perspectives, which are (i) nexus in project development (focusing on enhancing efficiency, viability and opportunity creation), and (ii) nexus in regional and national planning, focusing on optimising the region's resource endowment to improve its socio-economic growth (Leck et al., 2015). Multiple studies have focused on managing regional resources such as inter-basin water transfers, many of which are relevant to South Africa, and are listed in Table 1.

Table 1: Key Inter-basin Transfer Schemes of South Africa, adapted from Muller (2002).

Source basin	Recipient basin	Average current (million m^3/a)	Use
Vaal	Crocodile	615	Industrial, domestic (Rand Water)
Vaal	Olifants	150	Industrial (power)
Olifants	Sand	30	Pietersburg
Crocodile	Limpopo	6	Gaborone
Komati	Olifants	111	Industrial (power)
Usutu	Olifants	81	Industrial (power)
Assegaai	Vaal	81 (150 max)	Industrial, domestic
Buffalo	Vaal	50 (90 max)	Industrial, domestic
Tugela	Vaal	630	Industrial, domestic
Tugela	Mhlatuze	46	Industrial, domestic
Mooi	Mgeni	69	Industrial, domestic
Fish	Sundays	200	Industrial, domestic
Orange	Buffalo	10	Industrial, domestic
Orange	Lower Vaal	52	Industrial, domestic
Orange	Riet	189	Irrigation
Orange	Fish	643	Irrigation, industrial, domestic
Caledon	Modder	40	Industrial, domestic
LHWP 1A	Vaal	574	Industrial, domestic
LHWP 1B (Matsoku)	Vaal	60	Industrial, domestic
LHWP 1B (Mohale)	Vaal	300	Industrial, domestic
Letaba	Sand	19	Industrial, domestic
Riviersonderend	Berg	100 (130 max)	Industrial, domestic
Kubusie	Buffalo/Nahoon	120 max	Industrial, domestic
Sundays	Swartkops	40	Industrial, domestic
Letaba	Sand	27	Domestic

South Africa is a participant in the Revised Protocol on Shared Water Courses in the SADC, and is under an obligation to fulfil its commitments by means of cooperation with its neighbours in the managing of international waters in the interest of regional economic integration and security (DWS, 2013). South Africa shares four major transboundary rivers systems with six neighbouring countries, namely (see also Figure 3):

- Orange/Senqu system, shared with Lesotho, Botswana and Namibia
- Limpopo system, shared with Botswana, Zimbabwe and Mozambique
- Inkomati system, shared with Swaziland and Mozambique
- Usuthu/Pongola-Maputo system, shared with Mozambique and Swaziland

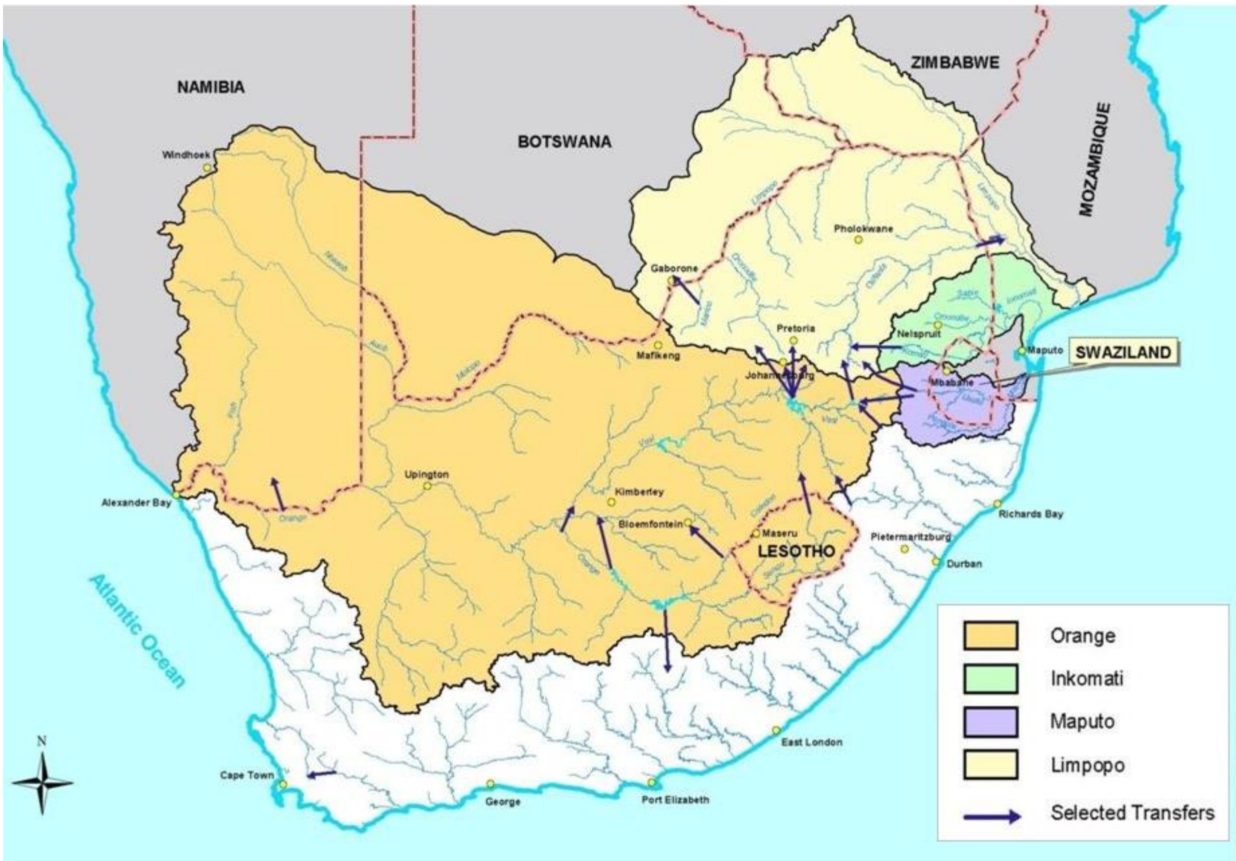

Figure 3: Transboundary river systems shared by South Africa (DWS, 2013).

Member states within the SADC have made advances toward conducting studies on transboundary water resources and formulating policies that govern transboundary river basins through the establishment of Transboundary Water Commissions such as the Limpopo Watercourse Commission (LIMCOM) and the Zambezi Watercourse Commission (ZAMCOM) (Mabhaudhi et al., 2016). A water transfer agreement between Lesotho and South Africa, the LHWP (Muller and Kleynhans, 2017), has been able to address South Africa's water scarcity through the transfer of Lesotho's abundant water resources to the Gauteng region while the revenue from the project has been able to assist Lesotho in developing hydropower capacity and improving water distribution within that country (The World Bank, 2016).

There is a critical shortage of available energy in the SADC region as most of the member states depend on hydropower (Conway et al., 2015; Schreiner and Baleta, 2015). The Democratic Republic of Congo (DRC), Mozambique and Zambia are almost completely reliant on hydropower for energy generation, whereas Botswana and South Africa are largely coal-dependent (see Figure 4). There is extreme pressure when allocating water for hydropower generation since there is a trade-off with food production.

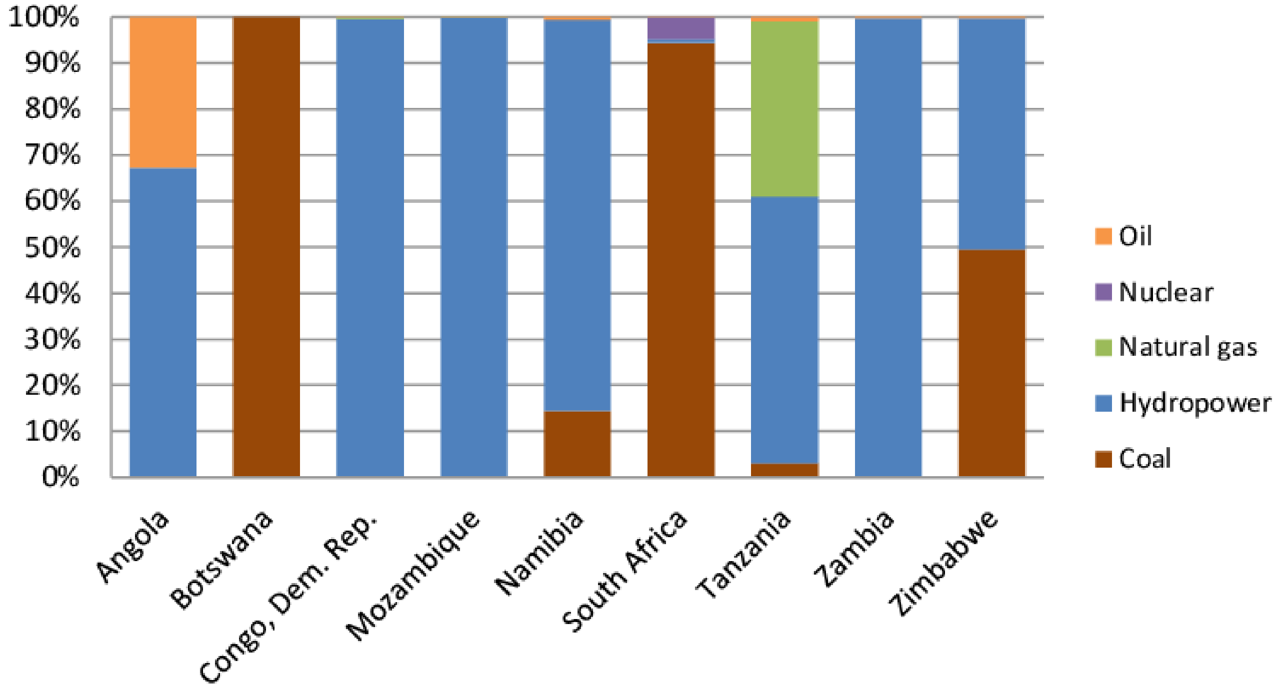

Figure 4: SADC electricity production sources. Retrieved from Schreiner and Baleta (2015).

Chronic food insecurity is prevalent across Africa, especially in Zambia and Namibia in relation to the population size as shown in Figure 5. Due to the recent increase in VAT to 15%, South Africans will likely experience increased vulnerability to food insecurity as well. The food security documentation from the SADC connects food production with rainfall, showing an awareness of how these two components of the WEF nexus are related. For the past two decades, floods caused by heavy rainfall significantly reduced crop production and yields in parts of Mozambique, Botswana, Malawi, Zimbabwe and South Africa. The impact of pests and diseases are currently considered to be negligible, however, the severity and incidents of pests and diseases are likely to change as a result of climate change and will vary based on geographical regions (Elad and Pertot, 2014).

The SADC has attempted to integrate water with food and energy by raising awareness on the issues and interdependence of these three sectors. As of 2015, the SADC has been engaging with relevant stakeholders and international cooperating partners to assist in understanding the nexus and its value in a southern African development context (World Water Forum, 2018).

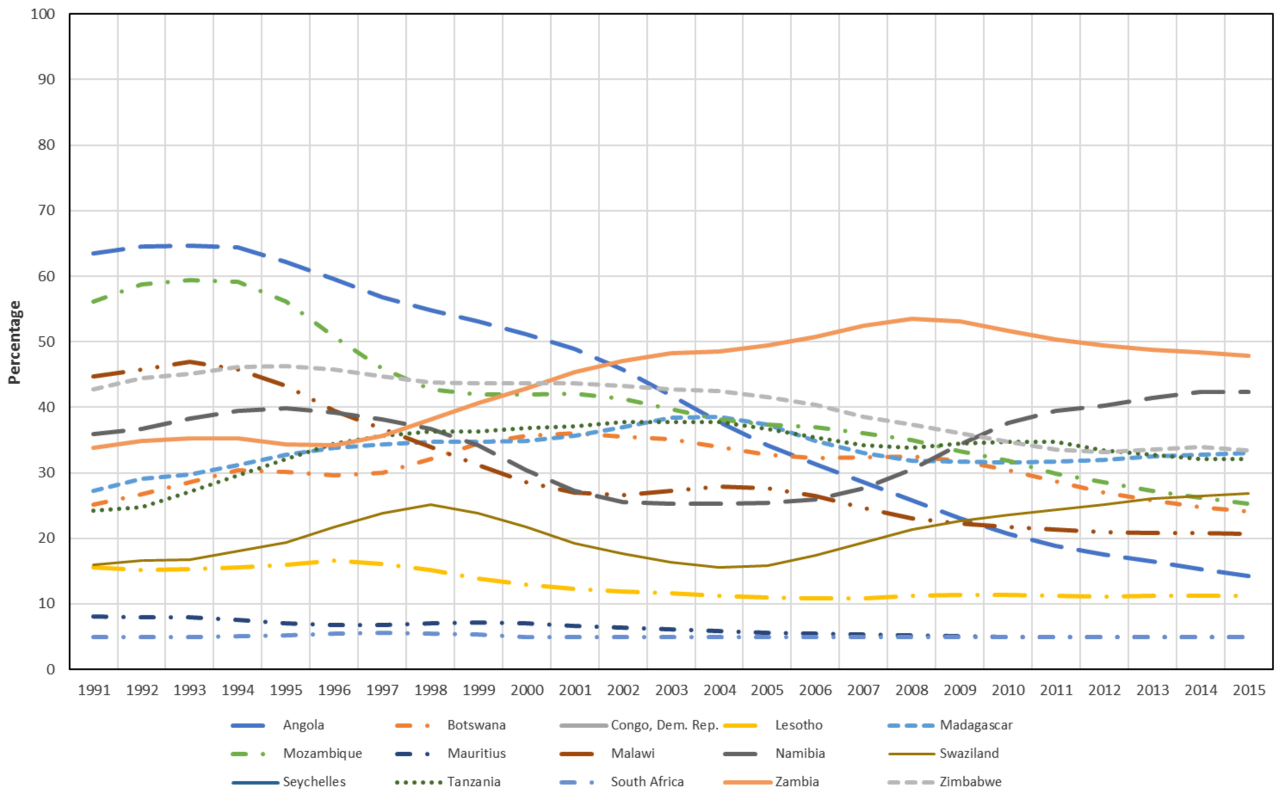

Figure 5: The prevalence of undernourishment in SADC countries in 1991 and 2015 (Mabhaudhi et al., 2017).

1.2.2 National

Most information that can be applied to the WEF nexus in South Africa is sector-specific, but it still provides essential knowledge from which the WEF nexus can be analysed. In 2014, the WWF-SA published a series of documents under the title *Understanding the Food Energy Water Nexus*, which was funded by the British High Commission in Pretoria. This series approached the WEF nexus from various disciplinary perspectives, investigating its relation to climate change, waste management, financial flows, and the integrated planning of the WEF nexus elements. As such, these documents have greatly contributed to the current knowledge of the WEF nexus in South Africa.

The WEF nexus is currently being investigated by several universities and institutions in South Africa, with the most prominent being the University of KwaZulu-Natal (UKZN) and the University of Cape Town (UCT). Current projects are presented in Table 2, and a list of national WEF nexus research "champions" is provided in Appendix B.

Table 2: WEF nexus projects, as identified in 2018.

Project	Project leader	Funded by	Commenced
Exploring the Evidence of Water-Energy-Food Nexus Linkages to Sustainable Local Livelihoods and Wellbeing in South Africa	In collaboration: ACDI (UCT), RVAC (UFH), and CWRR (UKZN)	WRC	2017
The Food, Energy, Water, Land and Biodiversity (FEWLB) Nexus project	UCT	British High Commission and the Cape Higher Education Consortium (CHEC).	2013 (ongoing)
DAFNE	International Water Management Institute (IWMI)	European Union	2017

With reference to energy, South Africa is currently taking advantage of its geographical location to develop renewable energy generation projects (see Figure 6). Wind-power generation and photovoltaic energy conversion are currently the most prevalent renewable energy projects, with relatively few concentrated solar power (CSP) and photovoltaic energy projects in the southern portion of the Northern Cape. Energy generated by means of biomass must be rainfed and not utilise irrigation (Nhamo et al., 2018).

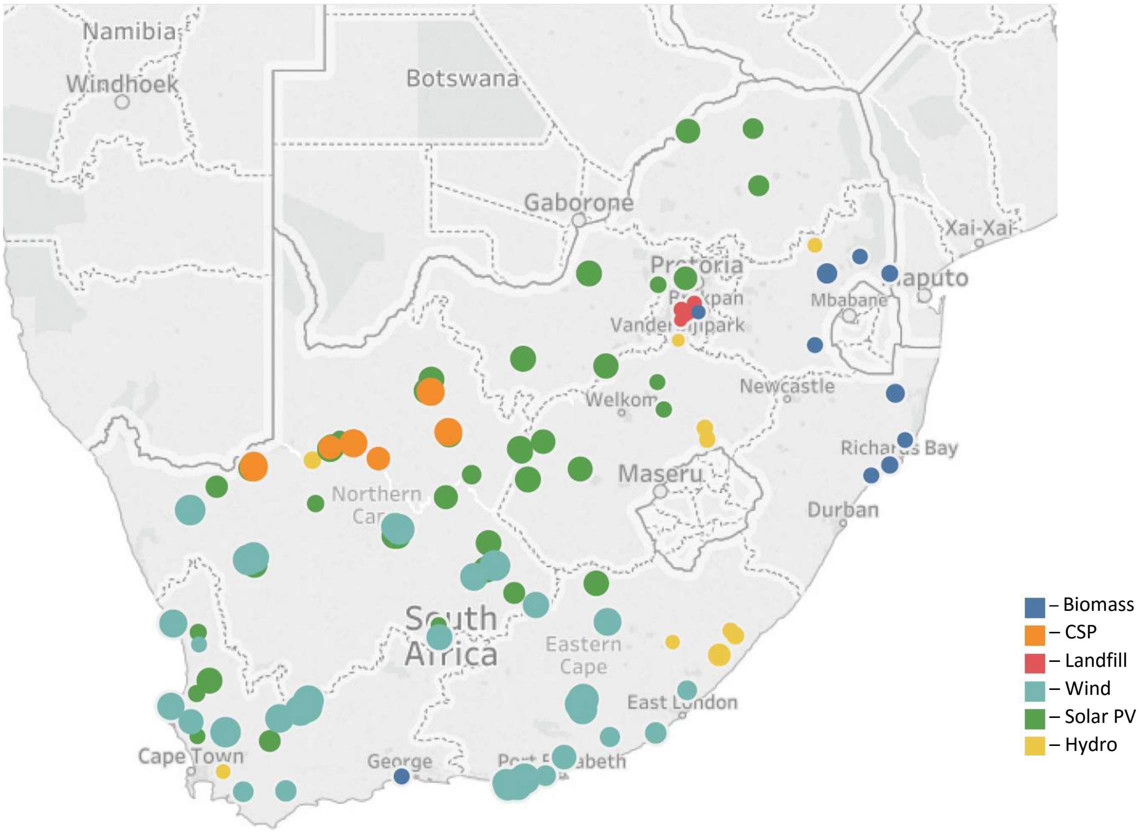

Figure 6: Renewable energy projects in South Africa, as at 2018 (REDIS, 2018).

South Africans are responsible for the generation of significant amounts of waste. Food waste can accumulate to a financial loss of R21.7 billion per annum, accounting for costs of lost food sources and the disposal of food waste (Nahman et al., 2012). Approximately 90% of waste generated by South Africans is disposed of in landfill sites, with only seven years' worth of landfill waste disposal space still available (DEA, 2012). Recycling, reusing and reducing waste will become central to the WEF nexus as it relates directly to all components within the nexus. Nationally, South Africa is one of the most advanced countries in terms of achieving the targets set in the three relevant SDGs, i.e. 2, 6 and 7.

Figure 7 shows changes in WEF nexus elements since 1999 in South Africa, showing a definite decrease in food deficit over time, and a positive trend for improved sanitation facilities, as well as access to improved access to both water sources and electricity. Simpson and Berchner (2017) state that South Africa is currently self-sufficient with regards to cereal production, that the prevalence of undernourishment is low (less than 5% of population), and that most of the population have access to clean and safe drinking water sources (in 2015, 93.2% of population has access to improved water sources) and reliable electricity (in 2014, 86% of the population had access to electricity, albeit predominantly fossil fuel based).

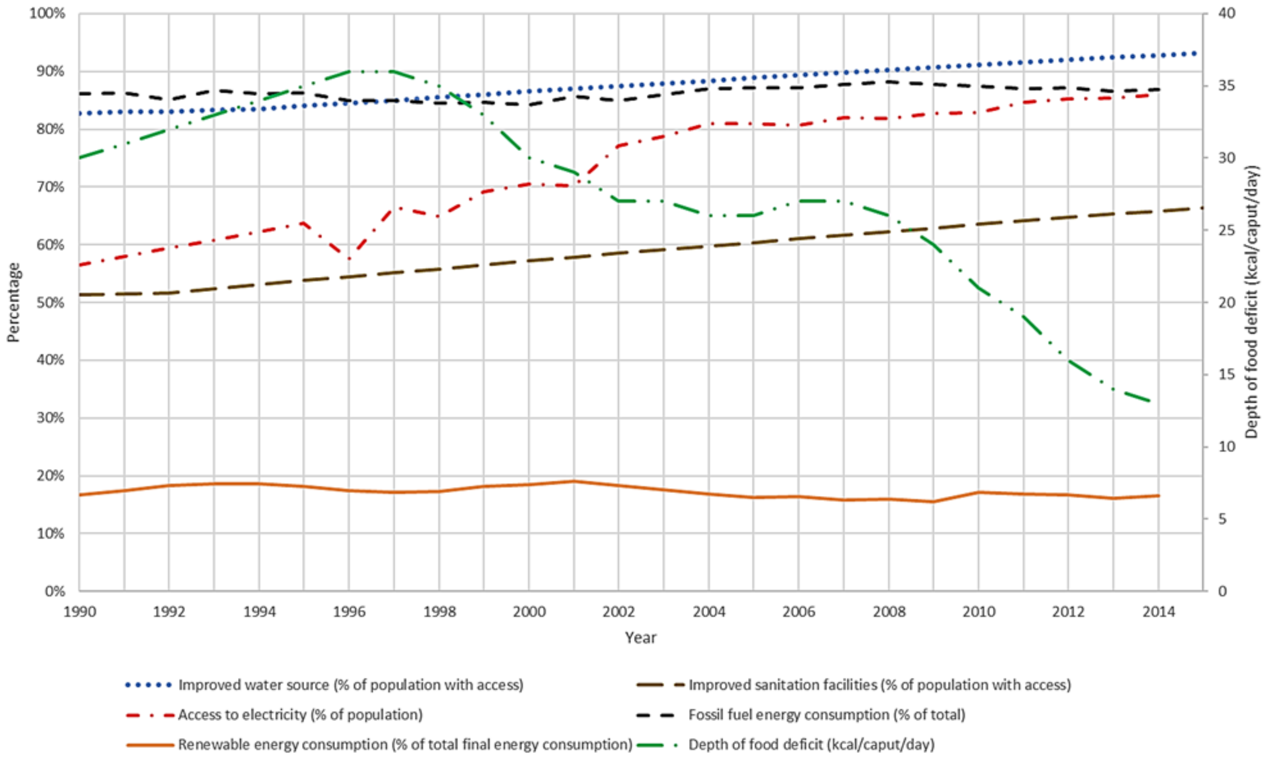

Figure 7: Annual changes in WEF nexus indicators (improved water source, access to electricity, renewable energy consumption, improved sanitation facilities, fossil fuel energy consumption, and depth of food deficit) from 1990 to 2014 relating to SDGs 2, 6 and 7 over time in South Africa (FAO, 2017; The World Bank, 2018).

1.2.3 Provincial

Gauteng is the smallest province in South African but is home to more than a fifth of the nation's population. Due to its remote location relative to significant water sources, Gauteng imports approximately 88% of its water via various inter-basin transfer schemes. The province contributes approximately 3% to the total agricultural production but consumes about 20% of these products. The electricity usage of Gauteng is high since it is the economic capital of South Africa, accounting for 24% of South Africa's total electricity delivered in March 2018 (StatsSA, 2018). This provinces' electricity is supplied predominantly by coal-fired power stations in Mpumalanga (Von Bormann and Gulati, 2014).

The Western Cape Province is responsible for approximately 25% of the agricultural sector's gross income, and exports more than 50% of its produce, 75% of which is destined for the UK and European markets. The provincial government has invested significantly to ensure good water quality within this region, as the potential loss of income from produce exports could account for anything between R190 million and R570 million annually (Von Bormann and Gulati, 2014). There is a debate on the sustainability of food exports, since this practice indirectly exports water from a water scarce area. In light of the drought that the Western Cape, and in particular Cape Town, has experienced in 2017/8, the sustainability of exporting 'virtual water' in agricultural products has been further questioned. These trade-offs need to be studied further to ascertain whether it will remain viable to produce and export fruit and vegetables, from a water perspective.

The Northern Cape experiences extreme arid climatic conditions, which is why only 2% of the province is utilised for crop farming. Stock farming accounts for 96% of the province's land utilisation, and includes beef, sheep and goat farming. The primary income generator in the Northern Cape is, however, mining. A major threat to the sustainable development of the Northern Cape is the spread of invasive alien plants, some using as much as 200 million m^3 water annually, which is then unavailable for farmers or rural communities (Hoffman and Ashwell, 2018). Agricultural land is further reduced by the spread of alien invasive plants, impacting food production potential. The total reduction in water flows in South Africa, as a result of invasive alien plants, is estimated to be 1 444 million m^3/year, or 2.9% of the naturalised mean annual runoff (C Le Maitre et al., 2016). If these invasive alien species were removed this water could be used beneficially for food production and domestic or industrial supply. Further, the removal of invasive alien species could function as a feedstock for energy generation from biomass, i.e. bioenergy, utilising for example the pyrolysis process.

In the Karoo, no large-scale electricity generation projects exist, and the region relies on small solar farms, or access to the national power gird. In terms of energy generation this region has been at the centre of much debate, specifically regarding unconventional energy sources such as shale gas or coalbed methane. To support drilling and hydraulic fracturing, water will be required. This is a very scarce resource in the arid, semi-desert Karoo, and there is a concern regarding the impact of these methodologies on both the quality and quantity of groundwater. Water resource systems and the supporting infrastructure within the Karoo are extremely strained. Only 14% (16 million m^3) of the storage capacity of the Welbedacht Dam is currently available due to unmitigated siltation (Ololade et al., 2017). Smaller towns in the Karoo generally depend on groundwater supply, which emphasises the potential threat that unconventional oil and gas (UOG) operations pose (Ololade et al., 2017).

1.3 Policy Framework

1.3.1 Water Sector

Water is one of the strategic sectors of the country, and several other sectors are dependent on the water sector to carry out their activities (e.g. energy and agriculture) (Mabhaudhi et al., unpublished). South Africa faces a mounting challenge to secure a supply of clean water, and to protect water resources (Madhlopa et al., 2014). The national government has developed a set of progressive policies and water sector-specific laws that should be properly aligned with the constitution for synergy (Madhlopa et al., 2014).

Based on the studies by Madhlopa et al. (2014) and Mabhaudhi et al. (unpublished), the following legislation, policies, strategies and plans relevant to the water sector have been identified, and are listed in Table 3.

Table 3: Legislation, policy and strategies for the water sector in South Africa (Mabhaudhi et al., unpublished, Madhlopa et al., 2014).

Document Name	Document Type
Constitution of South Africa (RSA, 1996)	Legislation
National Water Act 36 of 1998 (RSA, 1998a)	Legislation
National Environmental Management Act 107 of 1998 (RSA, 1998b)	Legislation
National Water Resource Strategy 2 (2012)	Strategy
White Paper on a National Water Policy for South Africa (DWAF, 1997)	Policy
National Climate Change Response Policy	Policy
National Development Plan	Plan
Water for Growth and Development (DWA, 2009)	Plan

1.3.2 Energy Sector

In South Africa, the energy sector is regulated by the Department of Energy, which has the constitutional mandate to administer legislation related to the energy sectors (Mabhaudhi et al., unpublished). For the purpose of this report, the policies, acts and strategies that have been identified for the energy sector, according to Madhlopa et al. (2014) and Mabhaudhi et al. (unpublished), are listed in Table 4. The existing policies in the energy sector have been driven by the need to promote industrialisation and economic development. The prioritisation of energy generation has often created new conflict, for example the expansion of coal mining in Mpumalanga which threatens food production and the broader environment. There is a need for greater alignment; the WEF nexus could be applied to align energy sector policies and improve sustainability.

Table 4: Legislation, policy and strategies for the energy sector in South Africa (Mabhaudhi et al., unpublished; Madhlopa et al., 2014).

Document Name	Document Type
National Energy Act 34 of 2008	Legislation
National Energy Regulation Act 40 of 2004	Legislation
National Environmental Management Act 107 of 1998	Legislation
Energy Efficiency Strategy	Strategy
White Paper on the Energy Policy of South Africa (1998)	Policy
White Paper on Renewable Energy (2003)	Policy
National Climate Change Response Policy	Policy
Integrated Resource Plan (2016)	Plan
Integrated Energy Plan	Plan
National Development Plan	Plan
Department of Energy Strategic Plan 2011/12-2015/16	Plan

1.3.3 Food sector

The eradication of hunger and poverty remains central to post-apartheid South Africa's policies (Mabhaudhi et al., unpublished). Similar to water, the right to sufficient food is also enshrined in the Constitution of South Africa (Section 27 (1)(b)) (RSA, 1996). This also remains one of the key SDGs within the ambit of the WEF nexus. Within this sector, agriculture plays a critical role in providing food, fibre and income to the rural poor (Mabhaudhi et al., unpublished).

In South Africa, the agricultural sector is regulated by the Department of Agriculture, Forestry and Fisheries (DAFF), with the Forestry and Fisheries departments previously being under other national departments (Mabhaudhi et al., unpublished). Table 5 lists key policies, acts and strategies within the agricultural sector in terms of their alignment to the water-energy-food nexus. The food sector policies have been driven by an incremental agenda, aimed at increasing production and food security. However, while national food security has improved, household food security continues to grow, which highlights a lack of sustainability. Also, the expansionist approach has often come into conflict with water and environmental managers. This highlights another opportunity for the WEF nexus approach to be applied.

Table 5: Legislation, policy and strategies for the food sector in South Africa (Mabhaudhi et al., unpublished).

Document Name	Document Type
Livelihoods Development Support Programme	Strategy
White Paper on Agriculture 1995	Policy
National climate change response policy	Policy
Integrated growth and development plan (IGDP) for agriculture, forestry and fisheries	Plan
Conservation of Agricultural Resources Act 1983	Legislation
Draft Preservation and Development of Agricultural Land Bill 2016	Legislation

1.4 Potential Application of The WEF Nexus in South Africa

1.4.1 Technical level implementation

Most WEF nexus research in South Africa has focused on policy implications and opportunities, with minimal investigations into the technical aspect of the WEF nexus. Technological approaches to the WEF nexus involve continually investigating more efficient solutions to sustainably managing resources. Precision agriculture combines information technology with rational agricultural practices to reorganise the farming system with the aim of achieving lower inputs, higher efficiency and sustainable agriculture (Shibusawa, 1998). Digital technologies would complement conventional farming methods by providing farm managers with rapid answers for achieving optimal planting densities and corrective nutrient balances of soil. There is much potential in South Africa for water reuse and recycling. Waste water from sewage, UOG and other industrial practices can be developed into reusable water with phytoremediation or water treatment plants, which would have otherwise polluted the environment, contaminating soil and crops. Optimising renewable resource use is a key technical approach to the WEF nexus that needs to be explored in South Africa.

In general, South Africa has much potential for renewable energy, particularly solar power generation. Figure 8 illustrates the ideal locations for various renewable energy initiatives, including biomass, photovoltaic, wind, hydro, and concentrated solar power. Areas that are predicted to have less rainfall could also be considered for renewable energy.

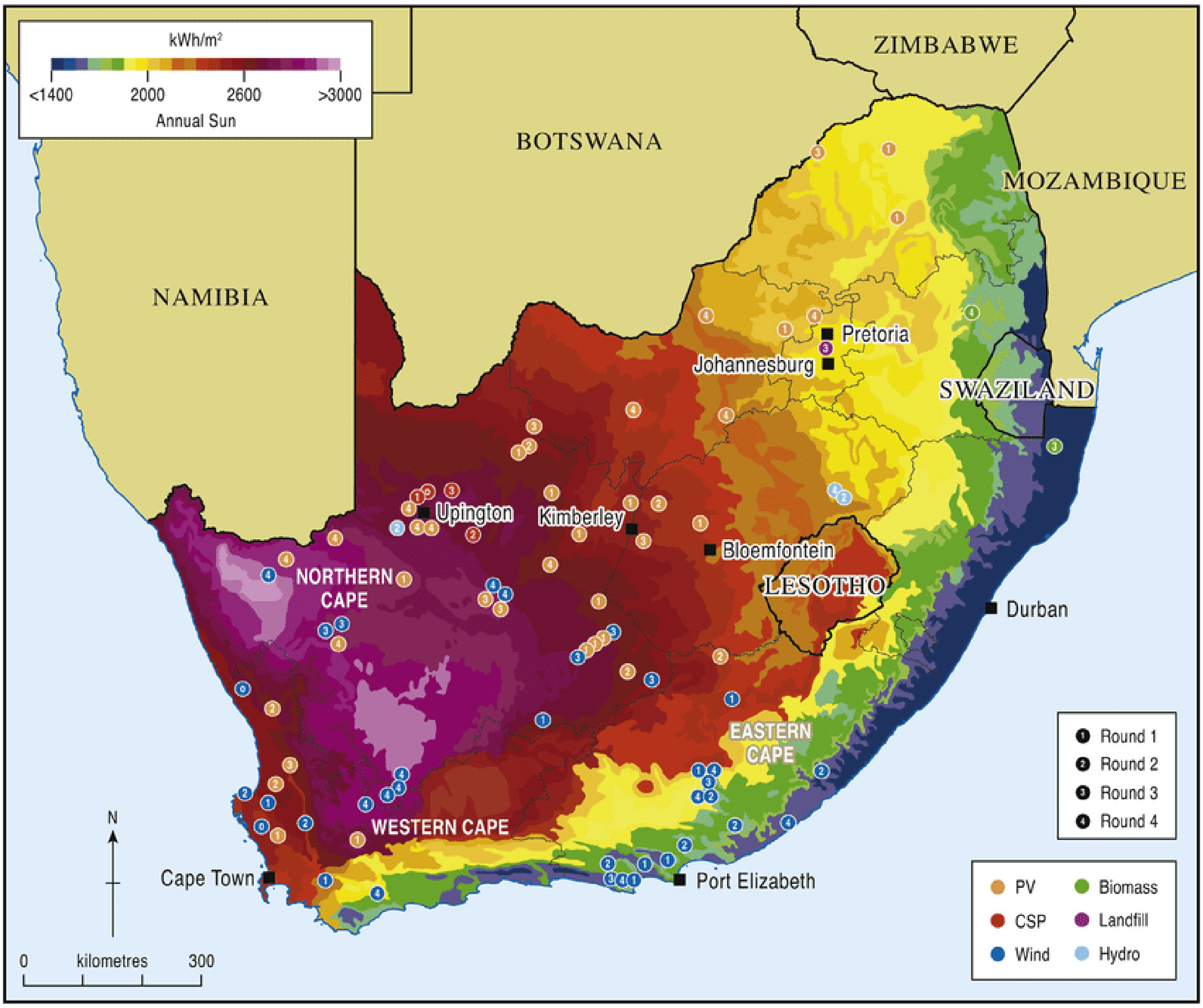

Figure 8: Current renewable energy projects in relation to land availability and annual sun (McEwan, 2017). PV – photovoltaic; CSP – concentrated solar power.

On a technical level, there is much potential for improving data collection, as well as the documenting, visualising and sharing thereof (Mabhaudhi et al., 2016). At a regional and national level, further studies and statistics on water demand are required. Cohesion between data-intense efforts from research groups such as Group on Earth Observation (GEO) and the United Nations (UN) is also needed to improve infrastructure and regional data requirements (Ozturk, 2015).

To improve energy efficiency and the reliability of supply networks, water utilities are focusing on distributed renewable energy solutions. In South Africa, eThekwini Water and Sanitation are exploring opportunities for the installation of mini-hydro plants that range from 100 kilowatts (kW) to 1 megawatts (MW) on existing water supply infrastructure to assist in improving system efficiency (IRENA, 2015). This project aims to realise the potential of renewable energy in water supply and treatment, maximising benefits from the infrastructure, reducing greenhouse gas emissions and allowing the framework to be shared amongst other municipal areas where the availability of water and power are a constraint.

The consequences of climate change could be an opportunity for certain regions in South Africa. Depending on the climate change scenario, maize yields may increase in areas with increased rainfall, or decrease in areas with reduced rainfall (Dube et al., 2013). One study indicates that maize production is predicted to increase due to climate change, even if harvesting areas will be reduced by about 25% between 2010 and 2050 (Johnston et al., 2012).

Furthermore, South Africans need to be educated and informed on the applicability of the WEF nexus. There are multiple opportunities associated with education including:

- Guiding households in waste management strategies, particularly food waste and recycling; and
- Guiding land owners in the sustainable use of their land, water and energy resources.

Degraded mining land presents an opportunity for renewable energy. Land that is unable to support food crop production could instead be used for bioenergy production. For example, post-mining rehabilitated land could support the growth of woody, salt-tolerant plantations with the intention of creating bioenergy (Wicke, 2011). Or rehabilitated opencast coal mines could be utilised for the development of solar energy farms, since their land capabilities will be significantly reduced because of the mining process.

General opportunities that could enhance the evolution of the WEF Nexus in South Africa include increasing resource productivity (rainwater harvesting, solar pumping, harvesting of invasive plants for bioenergy, desalination with renewable energy, applications of biotechnology), maintaining/managing natural ecosystems, and restoring (as far as reasonably achievable) degraded ecosystems, integrating poverty alleviation with green growth, and capacity building and awareness raising (Keairns et al., 2016).

Green technology and infrastructure, which includes recycling, renewable energy usage and sustainable buildings, will also influence resource availability in South Africa by reducing environmental pollution and improving the energy efficiency of households and businesses (Watson, 2013). Green infrastructure is defined as a set of natural ecological systems (or ecosystem services) that perform the same function as grey infrastructure without impacting on the natural environment, as well as the building of street-level designs that incorporates vegetation, like green roofs (Schäffler et al., 2013). An example is the sustainable use of wetlands for water treatment. The connection between the WEF nexus and green infrastructure in South Africa has been highlighted as an intergovernmental concern, wherein sustainability thinking should be embedded within city planning (Cilliers and Cilliers, 2016).

1.4.2 Policy level implementation

The most important application of the WEF nexus in South Africa is that its principles provide the opportunity to integrate the sectors so that issues may be resolved from a transdisciplinary perspective. Some have suggested that policy integration, relating to economic-, social- and governance aspects, may be more crucial for sustainable resource management than technological advancements (Mayor et al., 2015). An understanding of the interconnections of the water, energy and food sectors is critical for the development of a framework that connects all these sectors. The WEF nexus presents the opportunity for policy makers to assess the coherence of current water-, energy-, food- and climate policies, to ensure that the policies are interlinked and do not contradict one another.

Within the WEF nexus, movement towards a stronger framework can be achieved through multi-stakeholder dialogues within the water sector, along with interactions amongst the other sectors (energy, food, agriculture and resource divisions) through the revised Regional Indicative Strategic Development Plan (RISDP). There is scope for improvement from management and for information and interest to be generated at a technical level. Work is also required to present the WEF nexus better at a regional level with appropriate institutional strategies to tackle the interlinked challenges with particular focus on food and water at a regional level (Schreiner and Baleta, 2015). Non-energy sectors' demand for scarce water resources highlight the need for consolidated water-energy nexus planning at a regional level (Mabhaudhi et al., 2016). The Regional Strategic Action Plan (RSAP) makes specific reference to the WEF nexus and highlights how the SADC, with implementation of the WEF nexus, could adapt to challenges such as population growth, increased urbanisation, increased consumption demands and climate change (SADC, 2016). The National Development Plan (NDP) links to the SDGs, and emphasises that all people should have access to clean water (National Planning Commission of South Africa, 2012). These documents represent system-level thinking and may be key candidates for promoting the WEF nexus and its importance in policymaking.

Systems-level thinking is required given the complexity of the nexus, but it is not easily translated into government policy-making processes (Bazilian et al., 2011). Given this, it is critical to include policy-makers and researchers when revising or developing WEF nexus policies. For example, policies that improve the level of rural electrification may enable relationships between rural farming and non-farming activities to become stronger, which will lead to increases in agricultural growth and a reduction of rural poverty in the country (Ozturk, 2017). Guta et al. (2017) argue that Distributed Energy Systems (DES) need to be integrated into WEF nexus policies and that in the past, policies have overlooked the links between DES and the WEF nexus framework.

Those involved in policy-making processes need to keep in mind the adverse effects that climate change could have, and the implications thereof, on the WEF nexus (Carter and Gulati, 2014). Policy actions required need to simultaneously address the challenges of climate change, sustainable natural resource management, energy access, improved agricultural productivity, and supporting investments in technologies for improving water productivity and agricultural energy use efficiency (Guta et al., 2017). Carter and Gulati (2014) investigated the effects of climate change on food security in South Africa and suggested that policies should be focused on taking advantage of the positive effects of climate change (an increase in CO_2 and warmer weather will benefit certain crops) while reducing the negative effects. Policy responses could include supporting agricultural diversification and intensification, avoiding agriculture on marginal land, encouraging increased participation in markets within the small-scale sector and promoting sustainable practices to manage environmental resources (Johnston et al., 2012).

Research has shown that food security, water supply and energy are interlinked, and that intersectoral policies need to be developed for BRICS countries (Brazil, Russia, India, China and South Africa) to improve the food production, environmental quality and energy supply in these areas (Ozturk, 2017).

1.5 Challenges Facing the WEF Nexus in South Africa

1.5.1 Poor education, urbanisation, and poverty

The WEF nexus in South Africa may encounter several challenges that could hinder the effective implementation of its associated policies and guidelines. Inequality remains an issue, particularly in terms of access to quality education and resources. Despite more than 95% of children aged 6-15 attending school, the quality of education in South Africa remains very poor in the historically disadvantaged areas (SEACMEQ, 2017). Due to poverty and a general low quality of education prevalent in the country, many people tend to approach water, energy and food management in isolation to satisfy immediate needs. Investments, policies, isolated sectoral actions and weak governmental institutional capacity leave the linkages between water, energy and food relatively weak (Chirisa and Bandauko, 2015). Furthermore, the priorities of developing countries may not yet include the integration of the water, energy and food sectors. For instance, the high rates of unemployment and poverty challenges within South Africa are key drivers of the decision-making processes in the country (Goga and Pegram, 2014). It is commonly believed that poverty leads people to degrade the natural environment (Chambers and Conway, 1992) and in turn, environmental degradation affects poverty. Yet many studies indicate that the relationship is more complex than that, suggesting that culture and politics also play a significant role in environmental degradation (Duraiappah, 1998).

South Africa requires investors to drive infrastructural development relating to renewable energy, especially solar power, since much of the current capital is used to provide basic needs for the South African population. Recently, the DoE signed 27 Renewable Energy Independent Power Purchase Agreements (REIPPA), representing R56 billion's worth of investments from the private sector (African News Agency, 2018). The Northern Cape is potentially one of the best solar resource areas in the world (Edkins et al., 2010), but electricity production and transmission to electricity consumer centres will require large investments (Pegels, 2010).

According to Schreiner and Baleta (2015), the challenges facing the WEF nexus within the SADC region include population growth, development and climate change. Increasing affluence, rapid economic growth and urbanisation are escalating the demand for water, energy and food, especially in developing countries (IRENA, 2015). It is anticipated that by 2050, water and food demands will have increased by over 50% while the global demand for energy would have nearly doubled, leading to competing needs for limited resources impacted by climate change (IRENA, 2015). New strategies will be required to determine how the consumption and production of energy in relation to food and water sectors will be carried out.

1.5.2 'Silo' approach

The policies, strategies and plans of South Africa largely reflect a sectoral approach to managing resources. Many of these policies acknowledge the importance of the other sectors, such as the IWRM, but still neglect to give equal weight to water-, energy- and food security. Developed countries, like Germany, also suffer from silo-mentality when it comes to the implementation of nexus strategies or policies (GIZ, 2016). It is suggested by some that the sectoral approach is fuelled by internal rewards for those in powerful positions (Gyawali, 2015) and could be particularly prevalent in capital-rich sectors in South Africa, such as energy.

Many researchers and policymakers have attempted to eliminate trade-offs between and within sectors, but policies do not recognise intersectoral linkages, complicating resource availability when resources are allocated without consideration of other sectoral uses (Rasul and Sharma, 2015). The solutions for one sector may be detrimental to another, emphasising the need for coordination between water, energy and food policies.

1.5.3 Culture and politics

Cultural and political issues may be an obstacle to implementing WEF nexus policies in South Africa. It is uncertain what the response of communities would be in implementing WEF nexus policies due to the complex political setting and socio-cultural traditions in South Africa. Participatory approaches and increasing awareness and capacity building could induce interest in integrated resource management. Community participation has been shown to improve the long-term sustainability of DES and other sustainability projects (Guta et al., 2017). This indicates the importance of involving communities and stakeholders in initiating WEF nexus policies and practices and could potentially create entrepreneurial and work opportunities for South Africans.

National politics and policy-making processes will be complicated by trade-offs in the WEF nexus, especially when considering renewable energy options such as the use of biofuels and hydropower. For this reason, some actors prefer wind and solar energy (Conway et al., 2015). Trade-offs between the sectors may be the biggest challenge of the WEF nexus in South Africa, since none of the components is particularly abundant in the country. Within the water sector, water deficits and water quality are often recognised challenges (Goga and Pegram, 2014). Wicaksono et al. (2017) emphasise that the WEF nexus will encounter difficulties regarding the establishment of a sustainable development plan that considers all needs without producing a critical shortage of natural resources. This will be a challenge to coordinate as it will involve the water, energy and agricultural sectors of South Africa, each of which threatens the security of the other when viewed in isolation, highlighting the need for the WEF nexus to mitigate these threats between WEF sectors.

Simpson and Berchner (2017) report that the lack of coordination between sectors originates from a limited understanding of the nexus dynamics, which is demonstrated by the coal mining industry's significant impact upon high potential agricultural lands for energy generation. The development and implementation of the WEF nexus in South Africa is also constrained by inconsistent regulations, issues with power purchase agreements, poor monitoring, indistinct capability, lack of funding as well as an unbalanced distribution of natural resources (Goga and Pegram, 2014; Schreiner and Baleta, 2015). If the sectors remain isolated, climate policies may adversely affect WEF nexus security by aiming to reduce carbon emissions and substituting fossil fuels with hydropower or biofuels, leading to new water demands (Carter and Gulati, 2014; Leck et al., 2015).

The inadequate enforcement of the National Water Act will cause further stress on water resources, compromising agricultural and energy production (The World Bank, 2016). In the IPAP for South Africa, issuing of water licenses and land tenure are key constraints that have been identified relating to the WEF nexus (Goga and Pegram, 2014). Although the IPAP does not mention the issue of land reform, the NDP does highlight its importance, together with agriculture, food security, and access to clean water and electricity (National Planning Commission of South Africa, 2012). However, the NDP does not fully integrate resource management as it also states that irrigation and agriculture need to be expanded, but that it will not be done easily and significantly more resources would be needed. Land reform in South Africa has a risk in itself: farmers will be weary of investing in agricultural or land production if their tenure is not secure. The situation is further complicated by the current moves by government towards 'land expropriation without compensation'.

1.5.4 Climate change in South Africa

Climate change and its variability is recognised as a major challenge when considering the WEF nexus (Mabhaudhi et al., 2016; Schreiner and Baleta, 2015). Individual countries within the SADC display an increase in aridity, which increases the pressure on water demand for agriculture, water provision and energy production (Mabhaudhi et al., 2016). The issue of water scarcity is expected to be exacerbated with the threat of climate change. Climate change has significantly contributed to critical water shortages in many African countries, including South Africa (Campbell et al., 2014).Water is the most vulnerable element of the nexus that is affected by climate change (Wicaksono et al., 2017), yet there is a definite knock-on effect to the other sectors. It is projected that climate change will alter rainfall patterns and increase the frequency of extreme weather events such as droughts and floods.

Recent climate change reports indicate that sub-Saharan Africa will experience impacts of climate change through changes in water availability and rainfall variability (Mabhaudhi et al., 2016). Water is a finite resource and requires efficient use for crop production, which is generally the largest user of water resources. These changes will place further pressure on agriculture as increases in production, to feed a growing population and associated middle-class, will require corresponding increases in water demand (Mabhaudhi et al., 2016).

Water provision, food provision, and climate and pest regulation are ecosystem services that will be impacted by climate change, as shown in Figure 9. The benefits of considering ecosystem services within the WEF nexus emphasises the interlinkages of cultural, regulating and provisioning services and supports the intersectoral approach of the nexus. Fürst et al. (2017) concluded that the efficient use and conservation of ecosystem services on all decision levels will maximise the harmonisation of policies, planning and management required for sustainable development and WEF nexus implementation.

Linked to the climate change impacts is the rainfall variability that naturally occurs in South Africa, which complicates the WEF nexus inter-dependencies and the sustainable use of water in the country. According to Conway et al. (2015), the inter-annual variability of South African rainfall is relatively predictable when using models that include El Nino patterns and rainfall predictions, but it is unknown what effect climate change could have on the accuracy of these models. Furthermore, climate change will increase evaporation rates in areas predicted to have higher temperatures in the future, contributing to less perennial rivers available for thermoelectric- or hydroelectric power generation (Ololade et al., 2017). South Africa's rainfall variability, coupled with projected climate change impacts, is expected to lead to shrinking areas suitable for crop production and a rise in the unpredictability of farming conditions (Goga and Pegram, 2014). Figure 10 presents rainfall variability in Paarl, in the Western Cape, in recent years, which is an area prone to drought conditions.

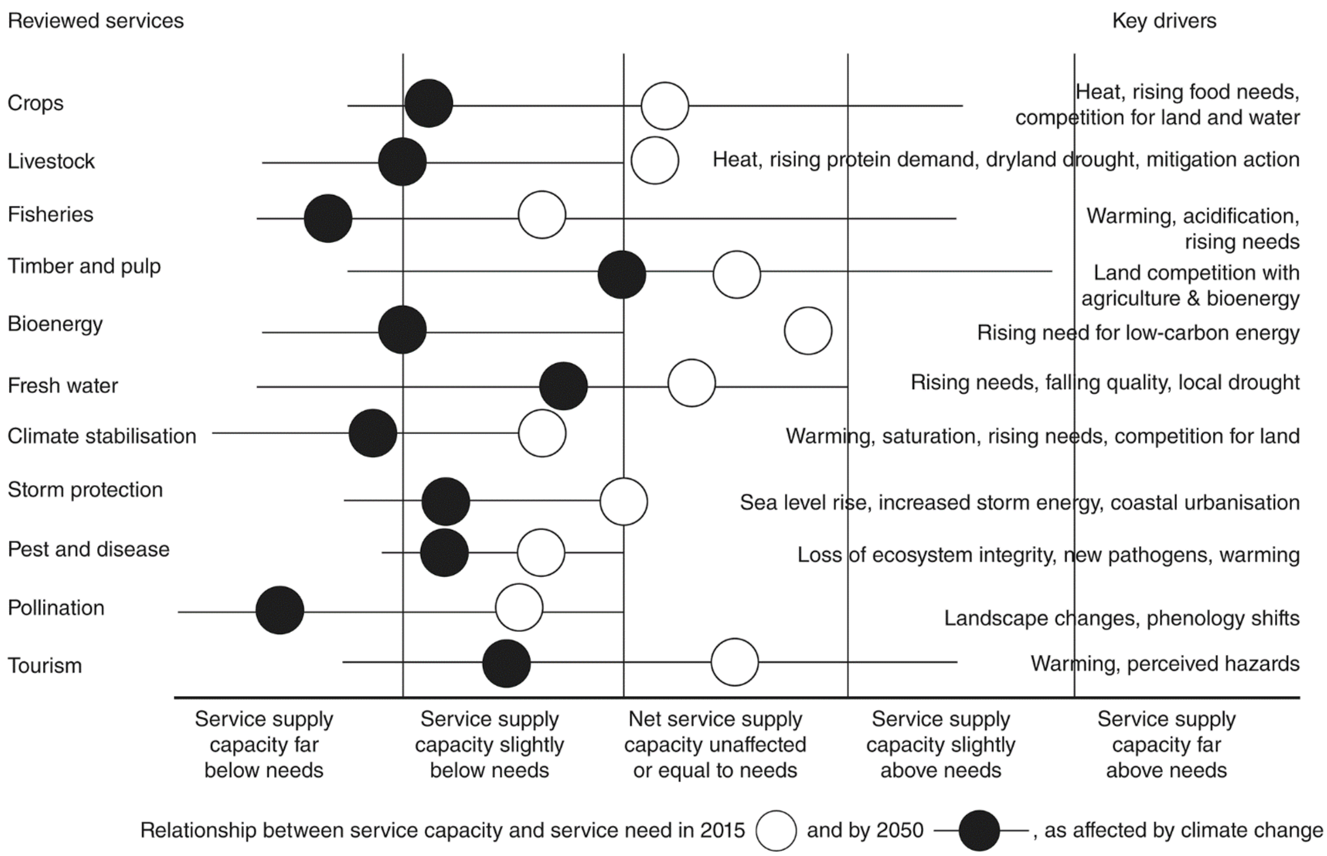

Figure 9: A visual representation of the relationship between some ecosystem services in 2015 and by 2050, as affected by climate change (Scholes, 2016).

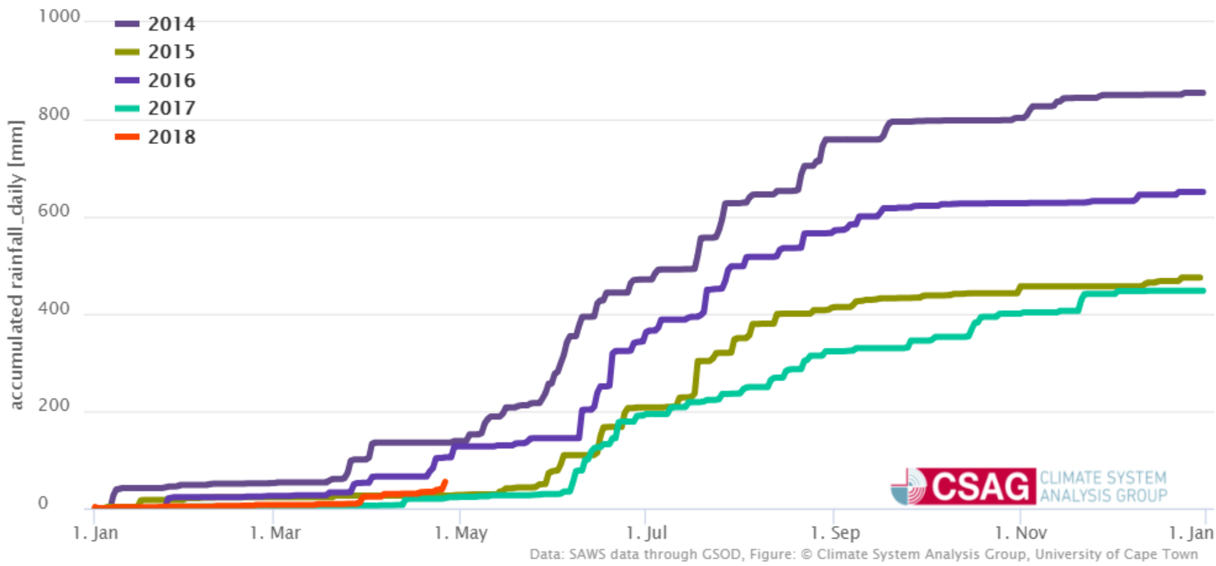

Figure 10: Accumulated daily rainfall at Paarl, Western Cape (CSAG, 2018).

1.5.5 Access to and distribution of data

Data availability and accessibility is a critical challenge to WEF nexus assessments worldwide. In circumstances where data are available, the data are often scattered, have different spatial scales (local, national, regional), possess limited comparability with other data sets or do not present temporal trends. Additionally, most WEF nexus tools are designed for thorough analysis of all three sectors. They therefore have significant data and resource needs (human and financial capacity). Rapid or preliminary assessment tools are also beneficial, are less resource and data intensive, and can provide answers within a timeframe that is in line with policy-making processes (IRENA, 2015). They are, of course, however less accurate.

1.6 Opportunities for Intersectoral WEF Nexus Planning

1.6.1 Private sector

The private sector was an early advocate for the WEF nexus concept. SABMiller are researching approaches to managing trade-offs between water, energy and food by endeavouring to make business decisions through a resource nexus lens (Conway et al., 2015). Other breweries and beverage producers, e.g. The Coca-Cola Company, have been paying increasing attention to the nexus approach for their own economic interest (Leck et al., 2015)

Internationally, the private sector has also been increasing their involvement in WEF nexus events and partaking in numerous WEF nexus-related public-private partnerships (Leck et al., 2015). Various initiatives exist that can provide an opportunity for the private sector to finance water and sanitation investments and be involved in designing and implementing water management and agricultural infrastructure interventions. Capacity building of the private sector involves developing and supporting small-medium enterprises (SMEs), and encouraging local entrepreneurs to partner in projects such as Water, Sanitation and Hygiene (WASH) initiatives that include the WEF nexus thinking.

1.6.2 Public sector

There has been a long history of WEF nexus thinking within the government, but it has not been made an official policy in South Africa yet. Political-economic considerations are remarkably under-represented in WEF nexus-related research, and this sector will need to be involved more thoroughly if sustainable policies and frameworks are to be developed (Leck et al., 2015).

To successfully address the nexus, social and political changes will be needed, which is seen as the real challenge in WEF nexus thinking. Stirling (2015) explain that new “infrastructures, organisations, behaviours, markets, governance practices and even cultures” will be needed to enhance the implementation of the WEF nexus.

1.6.3 Civil society

Collaboration between companies, governments, and civil society to promote and implement WEF nexus approaches is needed, and this is recognised by companies and authorities alike (Keairns et al., 2016). Numerous incentives are present for government, business, and civil society to implement nexus-thinking. These possibilities include improving financial efficiency by realising multiple SDGs simultaneously, and reducing the trade-offs and the risks of adverse cross-sectoral impacts (Keairns et al., 2016; Leck et al., 2015).

The recent WEF nexus meeting that included the civil society was the 8th SADC Multi-Stakeholder Water Dialogue, in November 2017, which was held in Johannesburg, South Africa. Apart from the civil society, the stakeholders present at the dialogues and workshops also included representatives from relevant government departments, as well as academia and the SADC Secretariat (World Water Forum, 2018).

1.7 WEF Nexus Links to the SDGs

The Sustainable Development Goals (SDGs) agenda builds on the achievements of the Millennium Development Goals (MDGs) and addresses areas that the MDGs did not achieve. The 2030 Agenda for Sustainable Development was adopted by the United Nations' Heads of State and Government for guiding the world towards a sustainable development path (Nhemachena et al., 2018). The seventeen SDGs target addressing social, economic and environmental problems facing countries by 2030 (FAO, 2016). Specifically, the challenges that triggered the development of the SDGs agenda include an increasing world population, climate change, increased urbanisation, environmental degradation and critical water shortages for domestic and agricultural purposes (Anderson et al., 2016). The SDGs are more focused on human livelihoods, with a total of 169 targets which are global in nature and universally applicable. Additionally, the targets recognise different national realities, capacities and levels of development and varying national polices. The SDGs agenda introduced an additional complex layer that recognises the linkages between the water, energy and food sectors. In the WEF nexus approach the three sectors are not only interdependent, but they impact upon each other (WWF, 2017). With regards to the WEF nexus, the most relevant SDGs are illustrated in Figure 11, and include: SDG 2 (zero hunger), SDG 6 (clean water and sanitation) and SDG 7 (affordable and clean energy).

Figure 11: The 17 Sustainable Development Goals agreed upon by 193 countries in 2015 (UNDP, 2015).

Literature has revealed that the evaluation of the SDGs in relation to food, energy and water can be regarded as an important tool to establish a holistic approach towards achieving sustainability and meeting the SDG targets (Yillia, 2016; Biggs et al., 2015; Gupta, 2017). Furthermore, the achievement of the SDGs requires decisions for nexus-based adaptations that take into consideration the need to build climate resilience in economic, social and environmental systems. A study by Simpson and Berchner (2017) proposed the calculation of a WEF nexus index using sustainability level indicators and population vulnerability in terms of each resource in the WEF nexus. Furthermore, human vulnerability indicators are key targets of the SDGs. It is also important to note that considering the SDGs through the WEF nexus lens makes it easier to understand the implications for other goals and accomplish targets across multiple goals (WWF, 2017). Since the implementation of SDGs is both directly and indirectly affected by socio-economic, environmental and political factors, the use of the WEF nexus as a framework to uncover these interconnections will increase the probability of the achievement of SDGs by 2030.

1.8 Policy and Research Gaps

Over the past few decades, natural resources management and environmental issues were mainly discussed by engineers and environmental scientists, in the absence of policymakers and other stakeholders (Wicaksono et al., 2017). The exclusion of policymakers and other stakeholders creates a large gap of knowledge between environmental practitioners and policymakers with regards to the sustainable utilisation of natural resources. Although countries around the world are at different levels of socio-economic development, they still face similar problems regarding development and sustainability. Some of these problems include food, water and energy across borders, thereby constructing interdependencies and linkages which increases the need for regional approaches and policies that aim at sustainable resource management. Nexus policymaking is about designing resilient government or business strategies in ways that take into account the connections between food, water and energy systems (Miller, 2014). Furthermore, for the development of sound WEF nexus policies and acts, there is a need for sustainable resource planning and management beyond government departments through a central authority such as the National Planning Commission (WWF, 2017). Such approaches will reduce the chances of formulation of policies and acts which recognise the importance of one sector at the expense of the others. Consequently, governance and joint compliance and enforcement structures are needed at local, provincial and national levels. Interdisciplinary studies between water-, energy- and food security are needed to address the knowledge gap, which is required for policy formation (Mabhaudhi et al., 2016).

1.8.1 Water sector

In the SADC region, the disconnect between regional energy and water planning is apparent since the two resources are often discussed at separate forums and regional policy lacks convergence (Mabhaudhi et al., 2016). The current National Water Act of 1998 emphasises the importance of stakeholder engagement and encourages partnerships, not only within the water sector but also extend the collaboration to the energy and agricultural sector on a regular basis. Since the energy and agricultural sectors have an impact on water quality, there is need for combined efforts on checking the decline of water quality and ensuring a commitment to the Polluter Pays principle as far as water pollution is concerned. Additionally, Catchment Management Agencies (CMAs), which manage water licenses and facilitate stakeholder engagement in important water catchments, are important for improving waste management policies and formulating an adequate water quality strategy.

1.8.2 Energy sector

The effective utilisation of energy resources within the WEF nexus requires collaboration across government departments to support the development of renewable energy generation as well as developing policy frameworks that recognise the implications of the energy sector on other sectors. The current National Energy Act 34 of 2008 does not recognise bioenergy and food as integral systems that are interdependent. There is need to consider projects that produce bioenergy, since these are potentially renewable sources of energy. Consequently, various benefits such as sustainable rural development, sustainable land use, and energy and food security for all can be achieved.

Additionally, a review of current energy policies would be the logical next step in implementing WEF nexus-thinking through adopting and recognising WEF nexus interactions and encouraging the development and upscaling of green technologies, especially if they are not heavily water dependent. These include trade-offs between hydropower plants and irrigation, or the use of agricultural land for food crops versus biofuel crops (McCornick et al., 2008). Therefore, WEF nexus policy research should focus on adjusting policy instruments by considering the WEF nexus in order to minimise and prevent conflicts between sectors.

1.8.3 Food and agriculture

There is uncertainty in the food and agricultural sector with regards to policies and plans that are directly linked to the WEF nexus. The NDP and the IPAP advocate for a substantial increase in agricultural productivity (Von Bormann and Gulati, 2014). On the other hand, policy action plans do not consider the fact that the expansion requires more land, water and energy resources. Consequently, there is need for policy makers to revisit the existing agricultural policy and factor in the implications of increasing agricultural productivity on water and energy resources. Carter and Gulati (2014) reported that there is a high possibility that water and agricultural policies may change, resulting in a potential risk to food production in the future.

To achieve positive outcomes within the WEF nexus, there is need to bridge the existing policy research gaps. This current study advocates for connections between WEF nexus academics and social policy makers to create capacity for evidence-based policy making. Additionally, a healthy WEF nexus will require the development of a sustainable agricultural policy through good land use planning, linking food production systems to ecosystems, designing a waste management policy as well as formulating a proficient water quality strategy.

1.9 Potential Indices, Metrics or Models for Evaluating the WEF Nexus

To accurately model and assess the WEF Nexus, it is useful to generate data that will be able to quantify flows of energy and materials, make numerical predictions and estimate the associated costs (Keairns et al., 2016). When developing or considering models to guide data generation, it is important to restrict the modelling scope to parts of the WEF nexus to eliminate complexity, but to be aware that there are risks associated with the possible omission of important interactions and to develop assumptions associated with these risks. To incorporate the necessary aspects of WEF nexus modelling, the involvement of stakeholders in the assessment process is also stressed, which may represent a trade-off between indicator-based assessments and elaborate numerical approaches (Keairns et al., 2016). The following section will present the indices, metrics and models that could be used to evaluate the WEF nexus.

1.9.1 Tools

The MuSIASEM (Multi-Scale Integrated Assessment of Society and Ecosystem Metabolism) tool was developed to simulate the WEF nexus by means of depicting the metabolic patterns of WEF in relation to the ecological and socio-economic variables. It was originally developed for an energy economy, but can be altered to evaluate the WEF nexus by including water and food in its accounting methodology (FAO, 2013). MuSIASEM allows the simultaneous use of demographic, ecological and social variables even if they are defined on different levels and scales. In this way, it allows effective analysis of the nexus between water, energy and food at a national or sub-national level. Furthermore, MuSIASEM provides feasibility, viability, and desirability checks of proposed scenarios. This tool was used to generate an integrated assessment of the contribution and convenience of CSP and woody biomass as alternative sources for electricity production in South Africa (LIPHE4, 2013). In this case study, quantitative data were used from various published research specifically evaluating the consumption of electricity in South Africa, as well as production factors of CSP and woody biomass-based electricity. The maximum short-term potential of CSP and woody biomass were calculated to be 3 000 GWh and 5 900 GWh, respectively, and would require the following:

Table 6: Requirements of production factors for scenarios concentrated solar power (CSP) and woody biomass-based electricity (LIPHE4, 2013).

Scenario	**Labour (Mhr/y)**	**Water (hm^3/y)**	**Land (ha)**
CSP	2.7	9.1	5 100
Woody biomass	120	NA	9 241 000

In Table 6, the MuSIASEM tool highlights the trade-offs between production factors such as water and land requirements.

The WEF Nexus Tool 2.0 was developed by the QEERI to evaluate the water, energy, land, financial and carbon production requirements for food supply in Qatar (Wicaksono et al., 2017). The WEF Nexus Tool 2.0 is a scenario-based tool that was created primarily to quantify the resources required for food supply at a national scale. The tool allows the user to create various scenarios by means of defining the inputs of water, energy and food portfolios. It has been applied in Qatar, where scenarios were created and assessed by calculating water-, energy- and land requirements, carbon footprint, financial cost, energy consumed though import, and carbon emission through import (Daher and Mohtar, 2015). Multiple scenarios are then generated, and the most appropriate scenario would depend on scientific- and policy inputs. Assumptions and limitations of this tool include:

- Food products assessed are only agricultural crops and exclude meat, dairy, etc.
- No calculations are incorporated to quantify effects on water and soil quality.
- Relationships between system components are based on empirically-based data.
- The tool assumes linear relationships between systems.
- The future projection of prices, population growth, and resource demand is not included.
- The existing tool does not capture the financial costs associated with the use of different water and energy sources.

The WEF Nexus Tool 2.0 presents an opportunity to evolve and develop with specific emphasis on South Africa. It may be further improved by including prediction analyses of population growth, resource demand increase and financial considerations.

A Sankey diagram has been used as a tool to represent the water and energy nexus by showing the distribution and connection of water and energy and quantifying flows in each stage of water and energy supply chains (Hu et al., 2013). The Sankey diagram has been used to visualise the water-energy nexus at a household scale in Australia (Kenway et al., 2013), regional scale in China (Hu et al., 2013) and at a national scale in the USA (USDoE, 2014). More recently, it was used to generate the relationships between water, energy and food for the United Kingdom, at a capital, government and household level, using multiregional input-output (MRIO) databases, as can be seen in Figure 12. With regards to its applicability for evaluating the WEF nexus in South Africa, it would provide a graphical representation of the complexity of the interlinkages between water, energy and food.

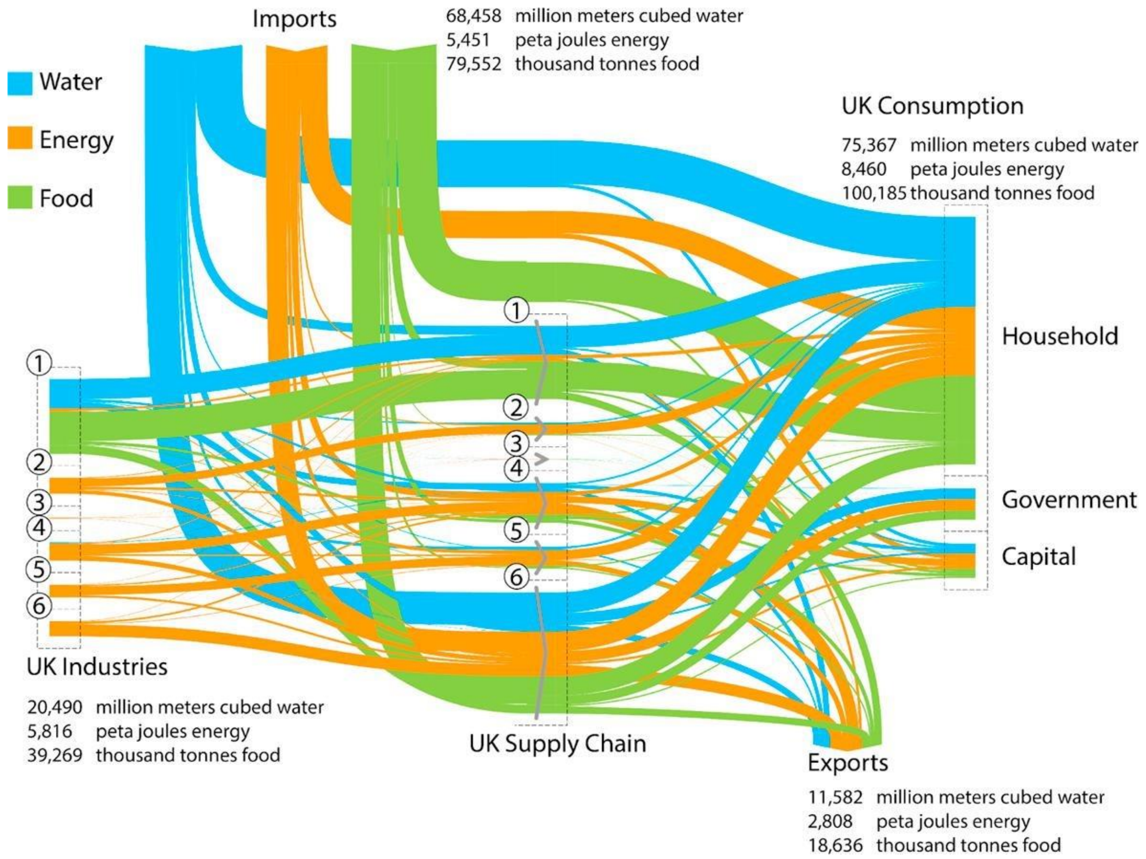

Figure 12: Sankey diagram showing water, energy and food flows, from industry to final consumption for the UK in 2013, where 1 = agriculture & food processing, 2 = power generation and distribution, 3 = primary materials industries, 4 = manufactured goods & recycling, 5 = transport, 6 = other services (Owen et al., 2018).

The Foreseer Tool (https://www.foreseer.group.cam.ac.uk) is an online tool that can be used to create Sankey diagrams.

1.9.2 Indices

The Nexus City Index (NXI), developed by the United Nations, considers food, energy and water resources and includes an equity index. The UN-Habitat approach developed indices to monitor the development of each of the key issues, namely i) productivity index, ii) infrastructure development index, iii) quality of life index, iv) equity index, and v) environmental sustainability index. These five indices are used to form the basis of the NXI, which exhibits the resilience of the urban water-energy-food systems. This approach is based on urban resilience, which is targeted in Goal 11 of the SDGs (Schlör et al., 2018). Along with the NXI_{region}, the World City Prosperity Index, the Regional City

Prosperity Index and a Regional City Index (NXI_{city}) were developed to assess the resilience of various regions and cities in the world (Schlör et al., 2018). These indices provide data and serve as decision support for identifying, monitoring, planning and managing the urbanisation process in cities and regions with special attention given to those developments within the WEF sectors (Schlör et al., 2018). These indices are useful in South African terms, but do not consider the impact of policy implications on the outcomes of the indices, nor do they include scenario-based predictions of population growth, climate change or economic growth.

1.9.3 Models

The SATIM-W model is a tool that provides insight into the trade-offs when evaluating the linkages between water and energy systems as part of cost-effective sustainable planning (Ahjum et al., 2018). As the name suggests, it is specifically applicable to South Africa, and incorporates large amounts of quantitative data relating to water supply, usage and costs (including water quality and treatment). Furthermore, scenarios include climate change impacts, economic growth, local environmental best practice, policy compliance, and low carbon technologies (Ahjum et al., 2018). To address the hydrological gaps of the model, the World Bank together with the SADC secretariat have launched a regional project to build sustainable groundwater management in the region (The World Bank, 2016). This model may be altered to include the 'food' sector of the WEF nexus as well as social aspects and has great potential to effectively evaluate the WEF nexus in South Africa.

The ANEMI model was established as an integrated assessment model that simulates all relevant variables, such as climate, carbon cycle economy, population, land use, hydrological cycle, water demand and quality (Davies and Simonovic, 2011). Specifically, the ANEMI model focused on revealing the interconnections and feedback of each element. The ANEMI model significantly improves the performance of previous models by including food production and enhancing the potential of optimising the energy-economy element (Akhtar, 2013).

Ozturk (2017) formulated simple non-linear regression equations using a set of explanatory variables of agricultural sustainability, to create understanding of the water-energy-food nexus, within a panel of six sub-Saharan African countries. The study utilised three separate panel regressions, that included the panel least squares regression ('common constant method'); fixed effects ('least squares dummy variables'); and the random effects model ('Dynamic Model').

The Climate Land-use Energy and Water Strategies (CLEWS) modelling framework aims to work with existing models and systems such as Water Evaluation and Planning (WEAP), Long-range Energy Alternatives Planning System (LEAP) and agro-ecological zoning (AEZ) by repeatedly simulating and comparing data between them to find a convergent solution (Keairns et al., 2016). It analyses interlinkages between different resource sectors to determine the effect that one sector might have on the others and identifies counter-intuitive responses in these integrated systems. It is a free online tool that create scenarios based on the following (UN DESA, 2013):

- Global estimates of CO_2 emissions, water use and investment in energy and material production,
- Estimates of CO_2 emissions and water use by energy source, and
- Estimates of mix of energy supply.

This model has been applied to a case study in Mauritius, focusing on two policy goals namely i) renewable energy production, and ii) renewable fuel standard mandating the blending of ethanol into gasoline. Similarly, case studies for Kenya and Bolivia were evaluated, investigating SDG 7 (energy access to all). If this model can be altered, it may be able to explore the WEF nexus in South Africa; however, it seems that it is mainly applied to the energy sector.

When contemplating the future development of WEF Nexus models and indices, Simpson and Berchner (2017) proposed the development of a composite indicator to report on the WEF nexus. Specifically, their study highlighted that the index should be based upon quantitative data and must be represented by a single numeric value, ensuring applicability the evaluation of different cities and countries. Mitigation scenarios could be tested to ensure the establishment of achievable and measurable goals to improve the WEF nexus index over time.

Apart from these tools, models and indices, data storage and accessibility will play a significant role in understanding and analysing the WEF Nexus. Furthermore, it is important to consider temporal and spatial scale differences of the WEF nexus elements, suggesting the need to integrate various available models and tools, as well as the influence of stakeholders and policymakers. Table 7, adapted from Martinez-Hernandez et al. (2017), summarises key models and indices that may be used for nexus evaluations, some of which have been discussed above:

Table 7: Potential models and indices that could be used to evaluate the water-energy-food nexus in South Africa, adapted from Martinez-Hernandez et al. (2017).

Tool	Modelling framework	Scale	System breadth	Analytical capability	Flexibility	Applicability to WEF nexus in South Africa
GLOBIOM	Dynamic multiregional partial equilibrium model	Global	WEF nexus and other interacting systems such as ecosystems	Geographically-explicit and long-term management of global land uses	Focused on land uses	No; only applicable at a global scale
WEF Nexus Tool 2.0	Input-output	National	WEF nexus components	Scenario-based for given food self-sufficiency level calculates nexus resource flows and interactions, and greenhouse gas (GHG) emissions	Focused on food as entry point and Qatar country	Yes
MuSIASEM	Input-output, nested hierarchical view of the economy	Aggregated to national or sub-national level	WEF nexus components, land, economy, human capital and ecosystems	Accounting of flows and funds and their ratios as indicators. GHG emissions and land-use	Adaptable to various contexts	Yes; it has already been applied to South Africa
CLEWS	Integrates detailed models from different tools (including WEAP, LEAP and AEZ)	National	Climate, Land, Energy and Water	Depend on the tools used for the CLEW assessment	Depend on the tools used for the CLEW assessment	Yes; if the model can be changed to evaluate the intersectoral influences of the WEF nexus components
Quantitative assessment framework	Input-output based on Lontief matrices	National	WEF nexus components	Scenario-based, accounting of nexus resource consumption	Fixed defined technologies and interactions	Yes; could be extended to analyse the influence of socio-economic factors

				and interdependency indicators		
DEA	Data Envelopment Analysis Model	Local (city level)	WEF nexus components	Input-output efficiency		No; cannot be used for national evaluation of the WEF nexus
PRIMA	Integrates regional climate, hydrology, agriculture and land use, socioeconomics and energy systems sector models	Regional	WEF components, economy, land use	Climate change related analyses and costs, land use, greenhouse gas emissions	Flexible, portable and modular	No; only relevant for regional decision-making
ANEMI	Integrated assessment model	All scales	Climate, carbon cycle economy, population, land use, hydrological cycle, water demand and quality	Reveals the interconnections and feedback of each element	System dynamic simulation	Yes
Sankey diagram	Graphically represents the complex conversion pathways, flows and interdependencies between variables	All scales	WEF nexus components	Based on the data input	Adaptable to various contexts	Yes
Nexus City Index	Measures the prosperity and sustainability of the FEW nexus for 69 cities	All scales	WEF nexus component, prosperity	A top down urban WEF nexus approach which aggregates the	Flexible, and includes likewise indices World City	Yes

				WEF sectors to a single indicator	Prosperity Index, the Regional City Prosperity Index and a regional city index	
MESSAGE	Modelling potential future energy scenarios	Global and Regional	Energy and greenhouse gas emissions	Dynamic linear programming model and can be linked with MAGICC (a separate program for predicting GHG-induced climate change) and GLOBIOM		No; does not consider all WEF nexus components.

1.10 Conclusions

The purpose of this review is to consolidate the available knowledge of the WEF nexus in South Africa, with a focus on its current status, challenges, and opportunities for intersectoral planning, at a technical- and policy-level. Furthermore, a WEF nexus framework was developed with emphasis on sustainable development goals 2 (zero hunger), 6 (clean water and sanitation) and 7 (affordable and clean energy). Current water, energy and food policies were reviewed, from which policy and research gaps were identified, and WEF nexus research champions were acknowledged. Lastly, the most relevant and applicable indices, models and metrics relating to the WEF nexus in South Africa were reviewed and summarised.

Based on the literature review, it is evident that WEF nexus research in South Africa emerged soon after the Bonn2011 Nexus Conference, suggesting a keen interest in and relevance of the subject. There is, however, limited information available. WWF-SA has contributed significantly to the understanding of the WEF nexus with its *Food Energy Water Nexus Study* series of 2014, and since then the topic has only re-emerged recently (2017) with the WRC and British High Commission funding the projects.

The application of the WEF nexus is particularly relevant when considering the recent proposed policy shift on land expropriation, which will significantly influence land utilisation depending on the policies associated with it. Currently, the various governmental departments – DAFF, DWS, DoE, DEA, etc. – generally approach resource management in isolation, without considering the usage of water, energy and land by other sectors. This is a major challenge in South African policymaking, especially when referring to the country's limited water availability, the scarcity of high potential arable land, and its reliance on fossil-fuel based energy generation. Furthermore, it is predicted that climate change will have a negative impact on the availability of resources in South Africa, where ecosystem services, rainfall frequency and distribution, and natural disasters will impact the reliability of the ecosystem.

CHAPTER 2

DEVELOPING A FRAMEWORK FOR THE WEF NEXUS IN SOUTH AFRICA

2.1 Applicability of Selected Existing Frameworks to the WEF Nexus in South Africa

A wide range of international initiatives exist that aim to frame the WEF nexus and define the close relationships that exist between the different components. This section of the project centres on creating a framework that can be utilised to bring about policy alignment and coherence for South Africa, with the WEF nexus as the framework and lens through which integrated resource management is assessed. A specific aim, considering South Africa's development status, is to yield a framework linking the WEF Nexus to the SDGs, placing emphasis on SDGs 2, 6 and 7. Land is a key consideration in South Africa. Another critical consideration is the incorporation of innovations in the WEF nexus since the identification of trade-offs and potential areas of conflict is not sufficient. Practical innovations are required to ensure not only resource security, but access the water, energy and food for all people.

A framework is an outline or skeleton of linked components which support a specific approach to achieving an objective. To develop the framework a methodology or procedure was decided upon by the project members during the project workshop that was held on the 26th April 2018 at the Centre for Water Resources Research (CWRR) at the University of KwaZulu-Natal, Pietermaritzburg. The methodology included the review of various existing WEF nexus frameworks to ascertain their applicability to South Africa.

In total, twenty frameworks were reviewed by the project team. The criteria utilised to evaluate the frameworks included:

- All three sectors: equal weighting (water, energy and food);
- Drivers of change (industrialisation, global change, population growth, urbanisation);
- Challenges facing South Africa (based on the above drivers of change);
- Applicability to South Africa (livelihoods [rural poverty], data requirements, sectoral compartmentalisation [governance/policy], fossil fuels, etc.);
- Integration (does the framework account for integration between the different sectors);
- Other sectors (does the framework acknowledge other sectors such as the environment/ecosystems, land, climate change, livelihoods, waste management, recycling/re-use?);
- SDGs and MDGs (does the framework account and connect to the development goals, i.e. for those published before the SDGs, do they refer to the MDGs?);
- Innovations (such as improved infrastructure, e.g. power stations, improved technology, etc.).

Based on these criteria, five existing frameworks were identified to be most applicable and were evaluated as follows:

Smajgl et al., 2016

The study by Smajgl et al. (2016) presented a sectorally balanced, dynamic, WEF nexus framework where sectoral objectives are given equal weightings. Analyses in the study showed that this type of framework reveals the emergences and/or changes in cross-sectoral connections because of single sector interventions. The dynamic WEF nexus framework describes interactions between (a) the three sectors as well as (b) between the nexus core and the three sectors (Figure 13). The nexus core in this framework consists of the drivers that are critical to the water, energy, food sectors and the cross-sector feedbacks.

This framework limits the interacting variables in the nexus core as it only considers climate change and population growth as the main drivers in determining the status of ecosystem services. The framework also displays how sectoral outcomes, feedback and control the attribute of core drivers thereby creating sustained interactions. Three distinct entry points are depicted on the framework, which introduce the sector-specific interests. This nexus conceptualisation aims for cross-sectoral coordination to avoid negative sectoral trade-offs and unintended side effects. The framework requires that the decision-makers and researchers account for sectoral interdependencies.

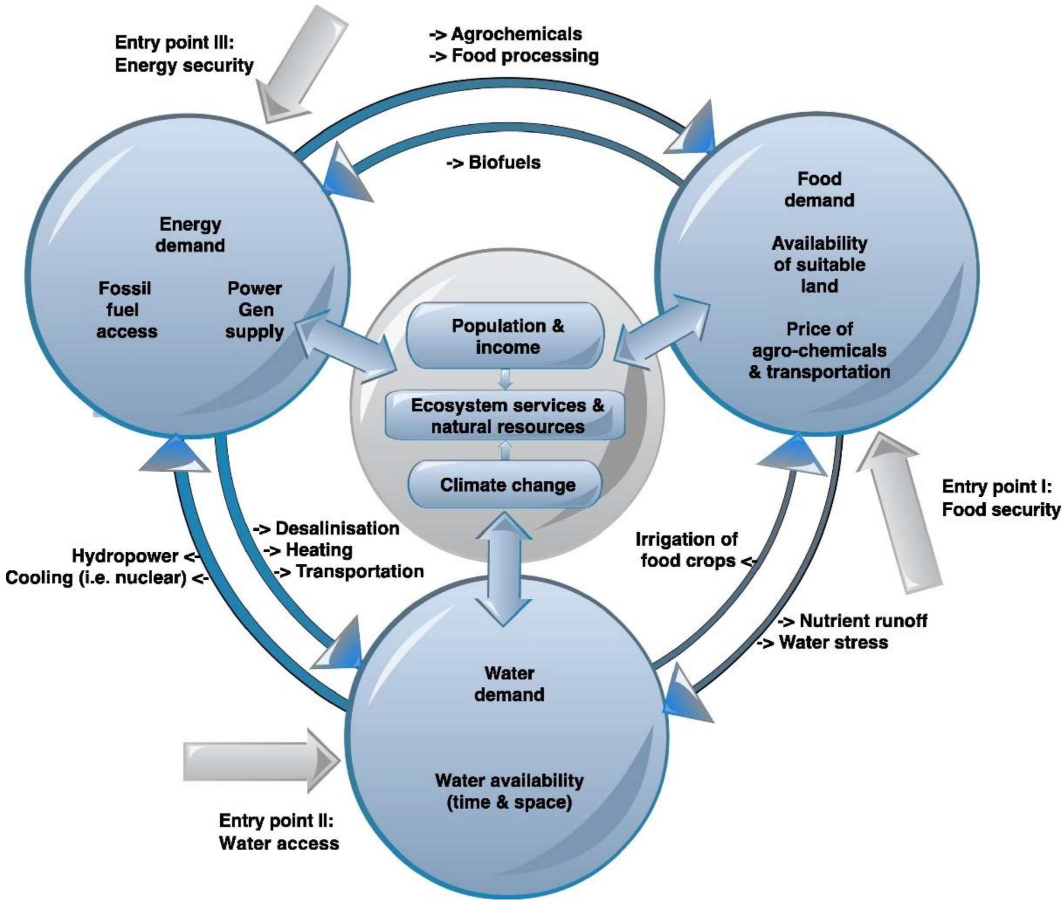

Figure 13: The energy-water-food nexus presented by Smajgl et al., 2016.

Ringler et al. (2013)

Ringler et al. (2013) present the concept of the water-energy-land and food (WELF) nexus. The study indicates that this concept is known to play out differently in various parts of the world. The WELF nexus framework evaluates the linkages that exist among the water, energy, land and food sectors (Figure 14). The direct and indirect drivers of change, which affect these linkages, are clearly depicted in the framework. In most existing WEF nexus frameworks, the land dimension in not included, however this framework considers the dimension of land as it recognises its importance not only in the production of food but also for water (underground water storage, reservoirs) and in energy supply (shale gas or biofuels). The study also sheds lights on the importance of land scarcity. Many WEF nexus frameworks have been illustrated as being water-centric; however, this framework puts food at the centre of the nexus.

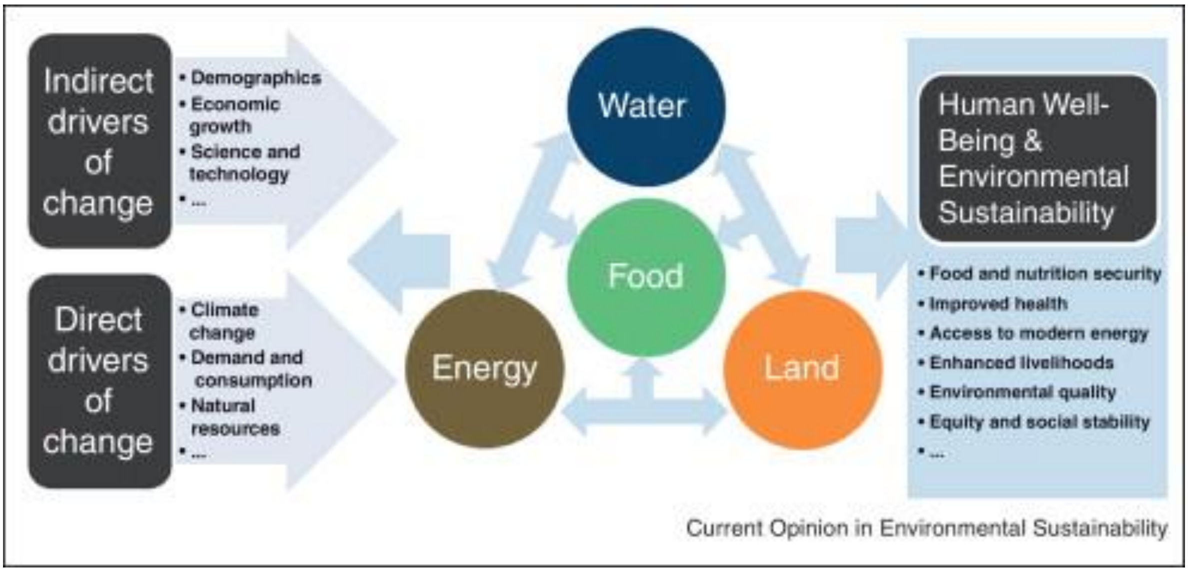

Figure 14: The extended water, energy, food and land nexus presented by Ringler et al., 2013.

Karabulut et al. (2018)

In this study, a synthesis matrix system is proposed which describes the complex and closely related relationships that exist between the natural resources used for food (specifically water and land), energy (which is defined as ecosystem service flows in the matrix system) and ecosystems, within the WELF concept. The matrix system can be defined for different scales (from global to local) and includes the impacts and nexus with climate change. The aim of the matrix is to integrate quantitative and qualitative aspects, which are often neglected in conventional approaches of impact assessment. Due to the complexity of interactions between the different components of the nexus, quantitative and expert judgement are both required.

In this framework, ecosystems represent the most significant component of the nexus as it incorporates all features that support water, energy, land and food availability and production. Due to ecosystems being a vital element to human well-being, they and their services are placed in the centre of the nexus (figure 15). This is also recognised through its incorporation into environmental policies and initiatives on an international level. Within the nexus, land is also included within the concept of ecosystems, since the term 'land' embraces different land users, land covers and soil ecosystems. In Figure, there are three matrices for the WEFL (water-energy-food-land) nexus in the form of a double entry table to identify the relationships between the sectoral uses of resources as well as the role of providing ecosystem services. Possible nexus service flows are listed and have been classified according to types/sub-types of sectoral uses, which refer to either final, or intermediate services that have a direct or indirect effect on human well-being. The main purpose of this framework was to build a frame around ecosystems and services to support the nexus approach, hence the concept being called the Ecosystem-Water-Food-Land-Energy (EWFLE) Nexus in this study.

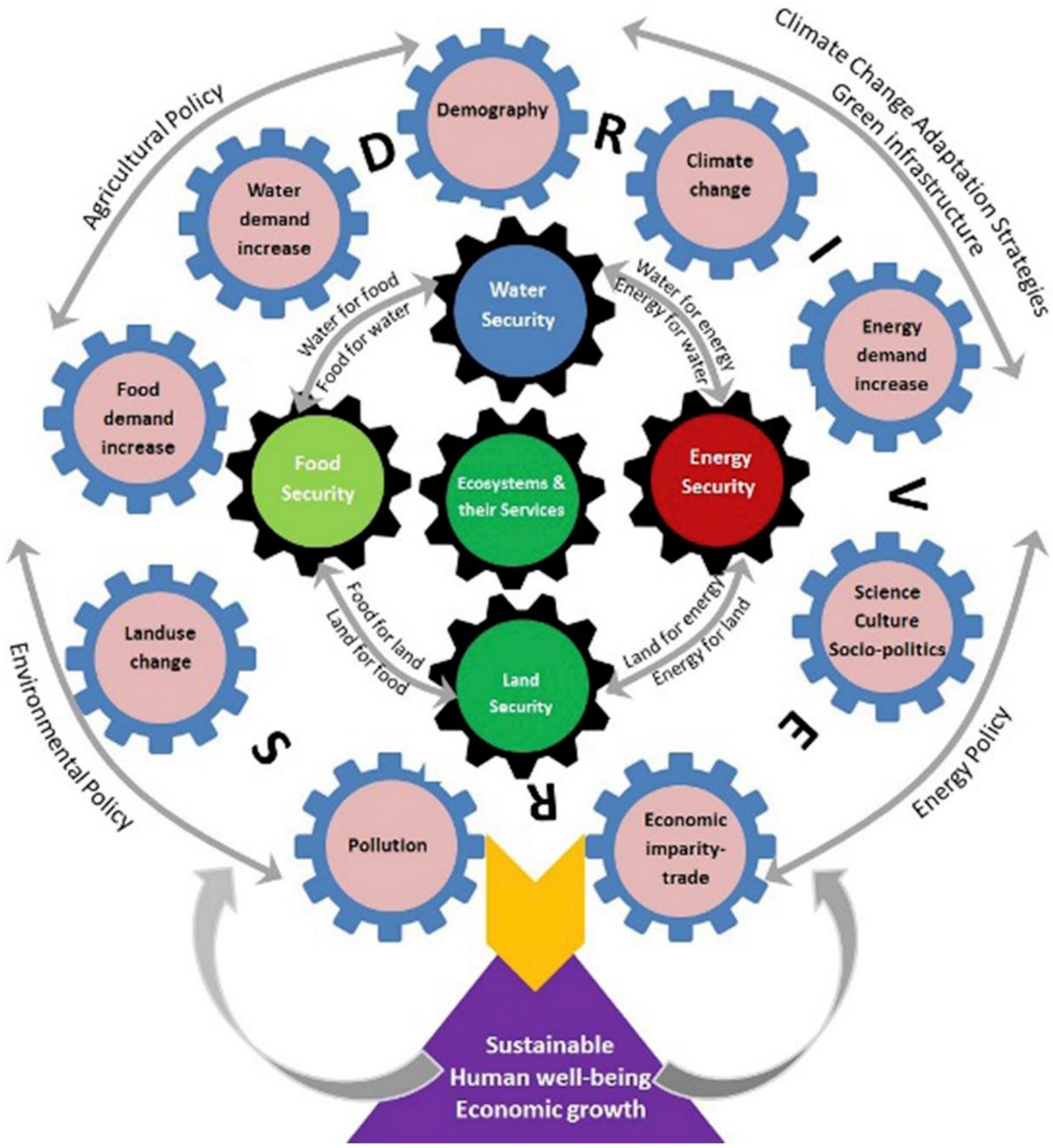

Figure 15: Framework for the ecosystem-water-energy, land and food security nexus presented by Karabulut et al. (2018).

Martinez-Hernandez et al. (2017)

A simulation and analytics framework, and a concomitant Nexus Simulation System termed "NexSym" is presented in this study. The purpose of this study was to develop a framework or tool for integrated resource assessment, accounting for integration within and across WEF sectors, ecosystems and consumption components that interact with a local system. Martinez-Hernandez et al. (2017) indicates that there is a need for a nexus tool on a local scale as solutions are better tailored to local conditions, and it becomes easier to achieve synergistic techno-ecological interactions.

The NexSym, which is a software tool allows an individual to explore how parts of a nexus are affected by a change in another part, as well as to evaluate the key interactions that may be developed into synergistic integrations. The approach in this study consists of a conceptual framework and a modelling framework, and the software structure. The scope of modelling takes into consideration energy, water and food production and waste treatment as well as the interacting components that are important for the WEF nexus such as ecosystems, consumption and other components of a local system. The approach combines data inputs, predictive models and integrated outcome analysis (Figure 16).

Overall, the NexSym models a local WEF system with three different types of components namely; ecological components (managed or natural ecosystems such as heathlands or forests), technological components (man-made industrial and municipal facilities) and consumption components ("sinks" of products and services, such as residential and commercial activities). This framework or tool is primarily developed for studying local systems, and it requires sufficient details of a locale to enable meaningful assessments to be carried out. The study further states that, "engagement with researchers and local communities to develop datasets specific to local contexts is crucial for the successful application of the tool".

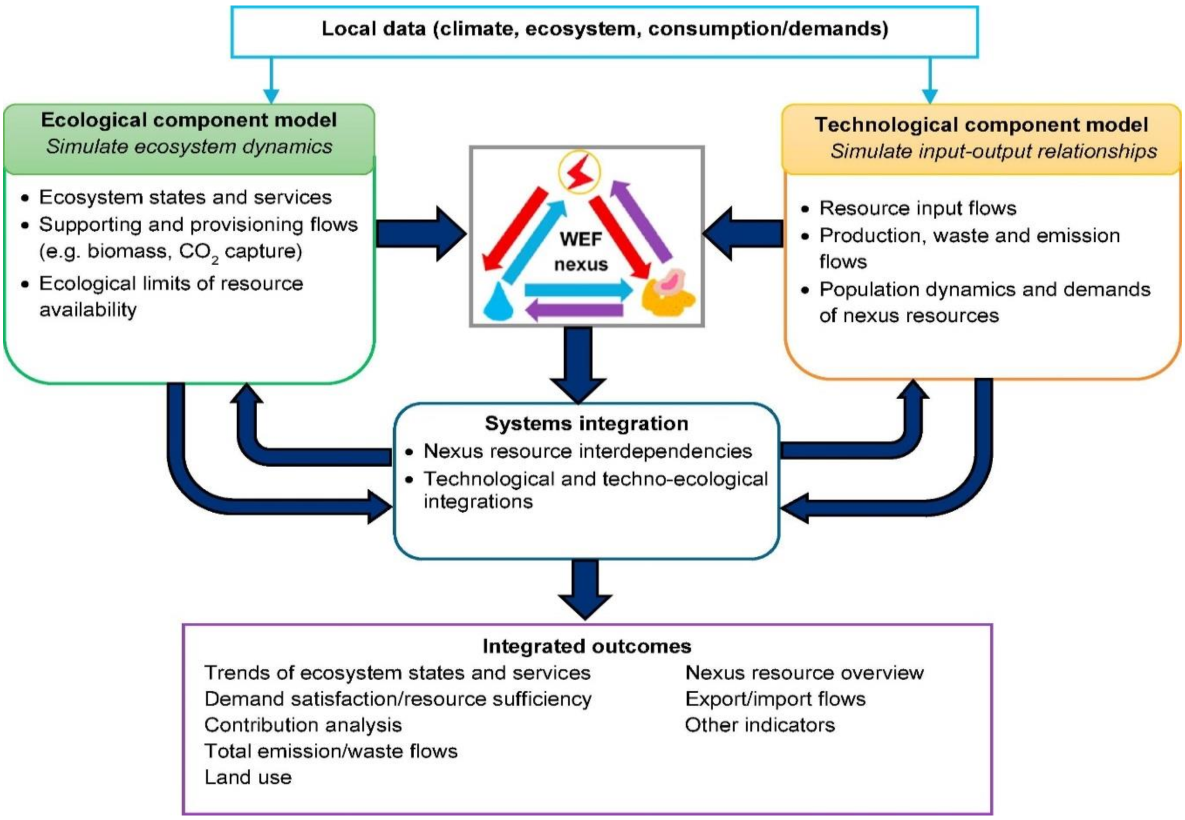

Figure 16: The NexSym model's intended input, output and techno-ecological view of the WEF subsystem and their interactions presented by Martinez-Hernandez et al., 2017.

Conway et al. (2015)

Conway et al. (2015) examined southern Africa's nexus from the perspective of climate and a modified Hoff's nexus framework (Hoff, 2011), which integrates global trends (drivers) with fields of action, to highlight the role of climate as a driver. The framework in this study considered the main elements of intra-regional links, which occur in WEF sectors at a national level, while highlighting connections on the river basin scale and drawing attention to case studies of the many examples of specific trade-offs and synergies.

Overall, the importance of climate in determining potential agricultural production, medium-term water availability and some components of energy production and demand are emphasised in the framework. In Figure 17, climatic variability drives fluctuations in the WEF elements, with secondary effects occurring across the whole nexus.

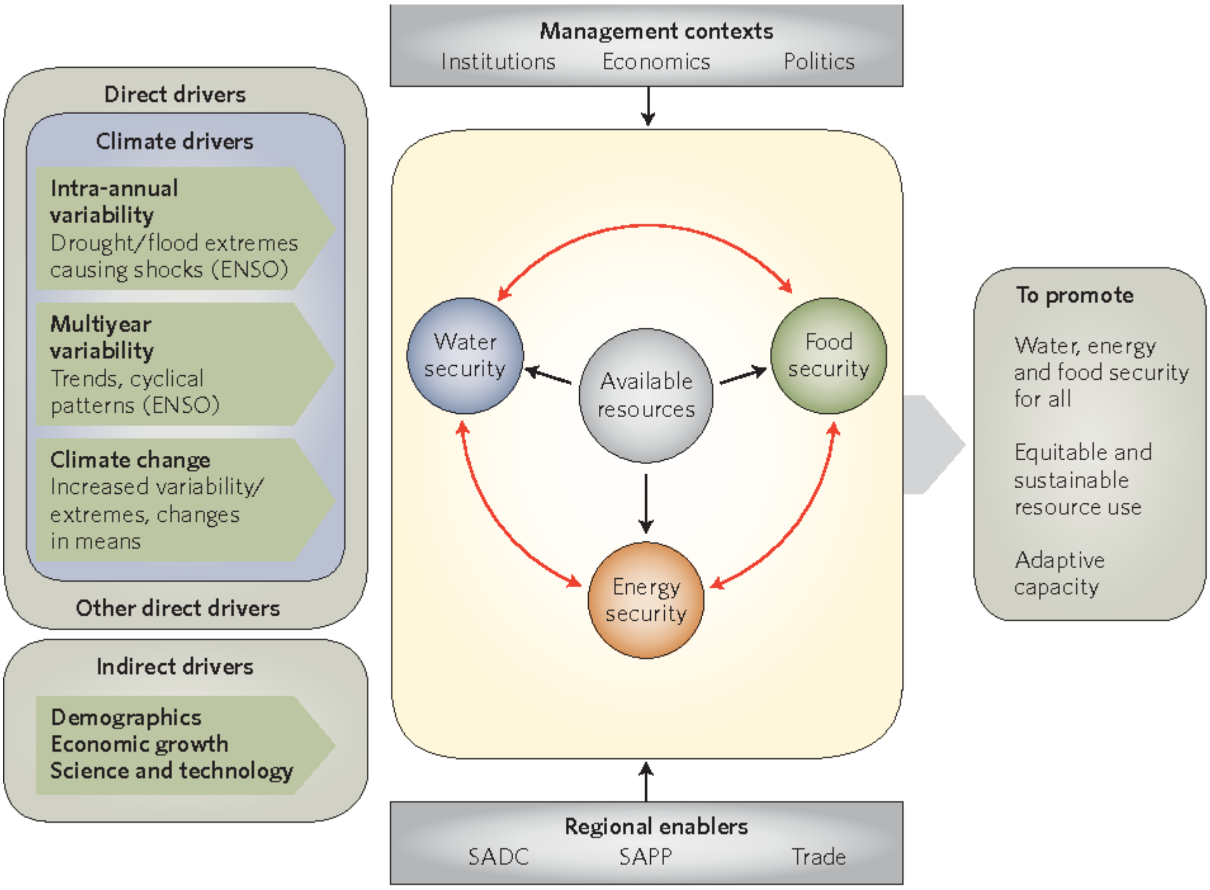

Figure 17: A modified version of the Hoff, 2011 nexus framework presented by Conway et al. (2015).

In evaluating these frameworks, consideration was given as to how the chosen or selected WEF nexus frameworks or tools can be modified so that they can be even more applicable for optimum use in South Africa. The WEF nexus framework put forward by Smajgl et al. (2016) scored relatively well and achieved the highest score when compared to other frameworks, indicating its applicability for use within South Africa. However, this framework did not include innovations to a large extent.

The WEF nexus framework presented by Ringler et al. (2013) scored the second highest total of the frameworks reviewed as being most relevant for use in South Africa. In order to be even more applicable to South Africa, this framework could be strengthened in terms of innovations and linkages to the SDGs.

In the Karabulut et al. (2018) study, the WEF nexus framework was ranked as the third most suitable framework for use in South Africa. It could be strengthened by providing more direct linkages to the SDGs, and through the inclusion of innovations.

The WEF nexus framework developed by Martinez-Hernandez et al. (2017) was ranked as the fourth most relevant framework, in the top five, for use in South Africa. The areas where this framework could be enhanced for applicability to South Africa includes more direct linkages to the SDGs, and through the inclusion of innovations.

The framework developed by Conway et al. (2015) in terms of applicability to South Africa, could be enhanced further through increased integration between sectors, stronger acknowledgement of adjacent sectors (e.g. livelihoods, land, ecosystems) and the inclusion of innovations.

Based on the review of the various frameworks, the project team sought to develop or modify the existing frameworks for more applicability and relevance to South Africa, and considered innovations, linkages to the SDGs, challenges, integration and acknowledging other sectors as key components to consider.

Innovations

A recommendation to improve the scores for this component within the criteria, and to make the frameworks more relevant and applicable for South Africa, would be to account for innovations such as improved infrastructure (e.g. power stations with lower emissions and/or dry-cooled power plants). In addition, renewable energy technologies (biofuels, wind, tidal and the use of abundant solar energy), technological advances (for data models and systems to develop as more data is required which will contribute towards a better understanding of the nexus approach and to inform decision making, for ease of disseminating and sharing data) are relevant innovations. Further possible innovations include working towards improving the efficient use of water (desalination, establishing dry-cooled power plants) as well as the option of seasonal climate forecasting (climate change adaptation for farmers).

SDGs

With the emergence of the SDGs, the WEF nexus has been recognised as a key tool for regional integration and development, as well as the actual achievement of the national SDGs targets (Mabhaudhi et al., 2016). It is also anticipated that SDGs will drive future policies since the targets of SDGs 6, 7, 8 and 9 are related to the water-energy nexus planning approach. The WEF nexus has been identified as an approach for achieving SDGs 2, 6 and 7.

SDG 2 accounts for zero hunger, SDG 6 refers to clean water and sanitation, SDG 7 focuses on affordable and clean energy, SDG 8 comprises of affordable work and economic growth while SDG 9 is aimed at industry, innovation and infrastructure. Hence, it is crucial that the frameworks mention and account for the above SDGs as well as illustrate how the SDGs connect with the three primary sectors under consideration. For example, SDG 2 can be achieved by eradicating food insecurity and improving nutrition. SDG 6 can be achieved by ensuring basic access to water and sanitation and tackling the issue of water scarcity. SGD 7 requires the promotion of renewable energy sources, and access to these power sources. SDG 8 focuses on job creation, educating the unskilled workforce, as well as working towards a sustainable economic development, while SDG 9 requires improvements in infrastructure, technology and industrialisation.

Challenges

With specific reference to studies by Karabulut et al. (2018) and Martinez-Hernandez et al. (2017), these frameworks scored low for the inclusion of key societal challenges and should take into account livelihoods (rural poverty, high rates of unemployment, educating the poor, electricity shortages, land issues), nutrition, health and food insecurity (agricultural sector). Furthermore, improving economic growth, water scarcity within the context of climate change, and data requirements and availability should also be included.

Integration

The framework by Conway et al. (2015) was amongst the top five relevant frameworks for South Africa that had the lowest score for integration, hence in order to modify the framework for applicability to South Africa, the framework should account for integration between the three sectors (water, energy and food) more strongly. Despite mentioning the three sectors, the framework should illustrate how the sectors merge as well as state possible solutions to improve integration.

Acknowledging other sectors

The WEF nexus framework by Conway et al. (2015), while serving its climate change focus, could illustrate or portray the connections and relationships between sectors, feedback and interlinks if it is to be more relevant to South Africa. While a WEF nexus framework cannot be all things to all people, if it is to be applicable to South Africa it needs to acknowledge and account for livelihoods, land, ecosystems/environment, climate change, waste recycling and reuse.

These recommendations are proposed in order to improve and modify the existing frameworks for better application to the context in South Africa.

2.2 A Proposed South African Based WEF Nexus Framework

Figure 18 is a schematic of a proposed WEF nexus framework for South Africa. The WEF nexus framework has been developed considering the issues relevant to South Africa, thus making the framework applicable for the country. As mentioned previously, a criterion was used to select the top five WEF nexus frameworks in terms of relevance to South Africa.

The top three frameworks by Smajgl et al. (2016), Ringler et al. (2013) and Karabulut et al. (2018) were used in conjunction with the framework by Hoff (2011) to assist in designing the WEF nexus framework for South Africa. Figure illustrates the vital drivers of change and challenges that South Africa must deal with, strongly influencing the WEF nexus. The figure also illustrates that with proper policies, strategies and the consideration of alternative clean, renewable options, a state of human well-being and environmental sustainability can be achieved. The WEF nexus framework had also been designed to incorporate SDGs 2, 6 and 7. The nexus framework describes interactions between the three sectors. The direct and indirect drivers of change, which affect these linkages, are also illustrated in the framework (Figure). The WEF nexus' core consists of the drivers that are critical to the water, energy and food sectors, and the cross-sector feedbacks in South Africa. Due to the aforementioned criterion, as well as being vital elements to human well-being, they are placed in the centre of the nexus.

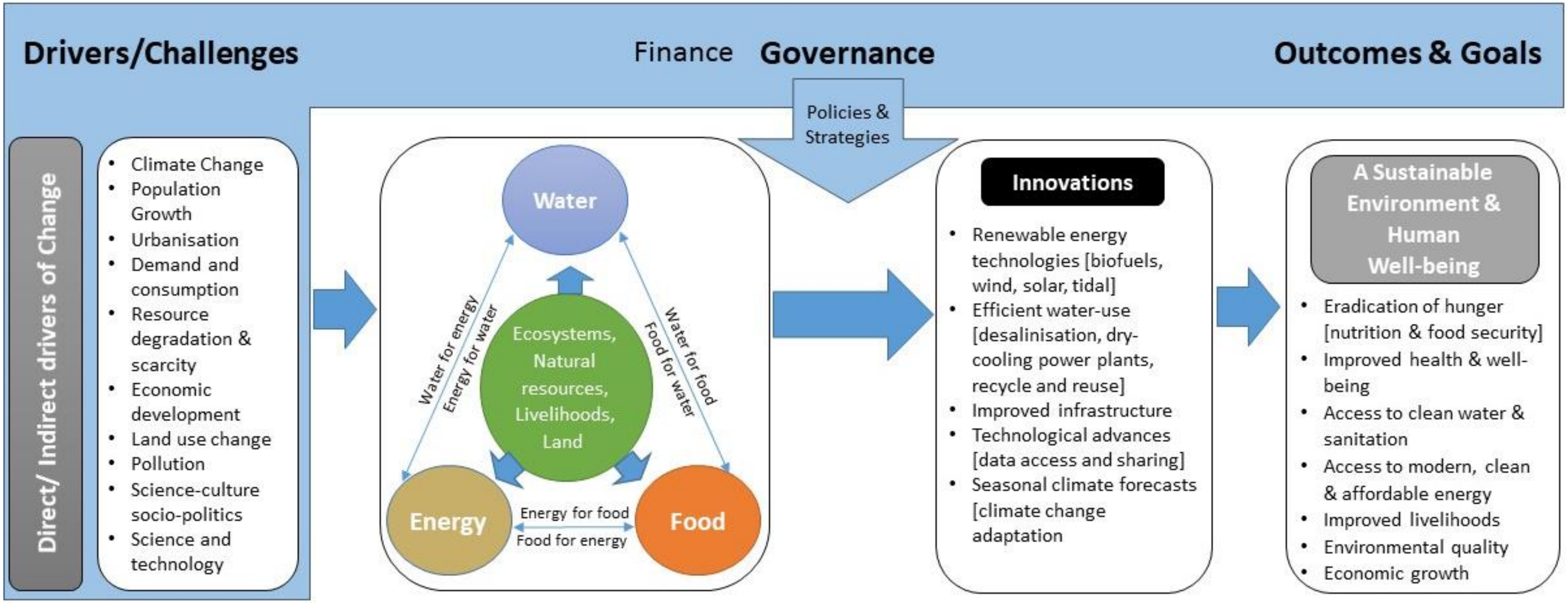

Figure 18: A Proposed WEF nexus framework for South Africa with particular emphasis on Sustainable Development Goals (SDGs) 2, 6 and 7 (modified after Smajgl et al. (2016), Ringler et al. (2013), Karabulut et al. (2018) and Hoff (2011)).

2.3 CONCLUSIONS

There are multiple models, tools and indices available to evaluate and quantify the WEF nexus; most of these tools may however require modifications to be applicable to South Africa. Data availability and quality will be a factor in the reliability of the models, emphasising the necessity of a central database where data can be compared and justified. The issue of temporal and spatial scale differences between data also needs further inspection and may be resolved by integrating various models and tools.

The status quo of the WEF nexus in South Africa is of great value, especially when developing a framework that is specific for the country. The WEF nexus framework that was designed in this project considers the importance of livelihoods and human wellbeing, an eminent threat to sustainable development, especially within South Africa. Current literature shows that policies, strategies and plans have not fully embraced the applicability of the WEF nexus to sustainable resource management with some documents only referring to its existence. More research is needed involving policymakers, researchers, and stakeholders to provide a comprehensive perspective on the desirability of implementing WEF nexus thoughts in South Africa.

CHAPTER 3

DEVELOPING A RESEARCH AGENDA FOR THE WEF NEXUS IN SOUTH AFRICA

3.1 Introduction

The WEF nexus in South Africa has not been explored to the extent that it would be implementable in governmental standards and policies. Many gaps in knowledge remain, and these must be addressed to develop WEF nexus adoption. It has become evident that in order to achieve SDGs 2, 6 and 7, the implementation of WEF nexus thinking is essential for resource allocation and future resilience, since the sectors are intimately dependent upon one another. Changes in one sector can have a profound impact on an adjacent sector. For example, should climate change reduce mean annual rainfall in a region, this will have an impact on both food and energy security.

Evidence-based decision making is required for sustainable resource management, yet information is lacking to fully inform policymakers and researchers. Particularly, trade-offs between the WEF nexus sectors need to be described, evaluated or monitored to the greater degree, such that they can adequately inform the development of policies, tools and guidelines. Future studies will necessitate not just quantitative assessments, but also the involvement of stakeholders and the collaboration of different governmental departments, specialists and policymakers. This component of the project presents a research agenda that aims to outline possible projects and studies that would enhance the WEF nexus body of knowledge within South Africa.

3.2 Proposed WEF Nexus Research Projects

The following projects, presented in no particular order, will aid in the future development and adoption of the WEF nexus in South Africa:

- Catchment-based assessments of selected Water Management Areas (WMA) utilising the Water-Energy-Food (WEF) nexus as a framework to identify resilient upstream policy recommendations
- An assessment of the potential impact of climate change on water availability, energy generation capacity and food production in South Africa during the 21st Century
- The development of a roadmap to achieve SDGs 2, 6 and 7 by 2030 in South Africa utilising the WEF nexus approach
- Water usage per energy generation technology type
- Fossil-fuel based energy security and food security in South Africa: When will the tipping point occur?
- A WEF nexus city-based metabolism study for Cape Town
- Potential sector-specific policy harmonisation to promote a WEF nexus approach to sustainable development in South Africa

- A study into practical household level application of the WEF nexus approach in South Africa, with a focus on rural, peri-urban and urban areas
- Water and land requirements for bioenergy implementation in South Africa
- A review of the availability of WEF nexus data at different spatial and temporal scales within South Africa
- The development of a WEF nexus index, and its application to South Africa and SADC
- A study of water scarcity implications for food- and energy security in South Africa
- A review of the applicability of available WEF nexus models to South Africa.

3.3 Recommendations

Intersectoral participation in effective policy-making may resolve many challenges and conflicts associated with the WEF nexus in South Africa. However, there is a need to disseminate WEF nexus knowledge among South African citizens and academics alike. It is recommended that future studies and research should investigate the following:

- **Developing an integrated model to assess the WEF nexus in South Africa, and creating a WEF nexus database**

A model or tool needs to be developed (or utilised or adapted) that will consider temporal and spatial scale differences of data, in addition to a WEF nexus database for South African information that should provide open access to the data. The information that may be added to the database could range from policies, standards and guidelines to quantitative data and published articles related to the WEF nexus. The availability of such a database could prove to be the driving force for promoting WEF nexus research.

- **Investment from the private sector into WEF nexus research, especially policy development and innovative green technologies**

The private sector should invest in WEF nexus research to drive the development and implementation of its principles, especially if incentives such as achieving SDGs, minimising resource trade-offs, and public private partnerships exist. Furthermore, green technology and infrastructure will become the standard for future developments as it will facilitate sustainable development. Innovation is required to produce more food with less water, and to accelerate both the implementation and access to renewable energy. The security of water, energy and food for all levels of society, including businesses, is going to become a vital planning concern in the coming decade, hence the World Economic Forum's active participation in this initiative since 2008.

- **Involving all parties (policymakers, researchers, and stakeholders) when developing policies for integrated sustainable resource management among the different departments**

Intersectoral policies should be the primary focus of the various departments of the South African government and should include input from stakeholders and researchers. This coordination is necessary in order to sustainably manage resources while considering a systems approach. The Department of Science and Technology's proposed *WEF Nexus Lab* could be a forum for catalysing these interactions.

- **Actively involving communities in WEF nexus projects to improve their understanding of the WEF nexus, especially among the poor**

Future projects need to actively involve communities and other interested and affected parties when conducting field studies or workshops to enlighten them on the importance of the WEF nexus using simplified diagrams and explanations, with practical examples that they can relate to. These communities, especially those individuals with no job opportunities, could be trained in developing and managing green infrastructure that will benefit their livelihoods while having managed negative impacts on the environment. A project highlighting WEF nexus innovations at a household level would provide vital input into such communication sessions

- **Policies and strategies for land reform should include the sustainable use of resources in connection to the WEF nexus**

Policies and strategies related to the WEF nexus can inform landowners on the sustainable management of their resources in the form of a land management plan so that they can benefit from the activities on their land. Emphasis is placed on the possibility of creating regional integrated land management plans for optimal land use for all landowners involved. This is particularly relevant for South Africa where the distribution of resources is unequal.

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APPENDICES

Appendix A: Systematic Review

Question and title formulation:

- *Question*: What are the status, potential, challenges and opportunities relating to the Water-Energy-Food nexus in South Africa?
- *Title*: A systematic review of the water-energy-food nexus in South Africa.

Review Scoping:

- Search terms: water; energy; food; nexus; South Africa; Southern Africa

Develop Search Strategy:

- Search online databases:
    - EBSCOhost
        - Boolean search: Water AND energy AND food AND nexus AND ((South* AND Africa) OR (sub-Saharan AND Africa) OR SADC)
        - Search date: 16/03/2018
        - 11 results
        - Publication dates: 2015-2018
    - Web of Science.
        - Boolean search: Water AND energy AND food AND nexus AND ((South* AND Africa) OR (sub-Saharan AND Africa) OR SADC)
        - Search date: 16/03/2018
        - 42 results
        - Publication dates: 2011-2018
    - Science Direct
        - Boolean search: "water-energy-food nexus" AND "South Africa" (alternating WEF terms)
        - Search date: 16/03/2018
        - 36 results
        - Publication dates: 2011-present
    - Scopus
        - Boolean search: Water AND energy AND food AND nexus AND ((South* AND Africa) OR (sub-Saharan AND Africa) OR SADC)
        - Search date: 16/03/2018
        - 24 results
        - Publication dates: 2011-2018
    - Wiley Online Library
        - Boolean search: "water-energy-food nexus" AND "South Africa" (alternating WEF terms)
        - Search date: 16/03/2018
        - 47 results
        - Publication dates: 2011-2018
    - Agricultural & Environmental Science Database
        - Boolean search: "water-energy-food nexus" AND "South Africa" (alternating WEF terms)

- Search date: 16/03/2018
- 64 results
- Publication dates: 2013-2018

o No. of academic articles: 11 + 42 + 36 + 24 + 47 + 64 = 224

Remove duplicates:	177
Articles to be excluded based on title:	109
Articles to be excluded based on abstract:	83
No. of journal articles to be considered for SR:	**26**
No. of articles for which full text could be found:	**23**
Add grey literature:	**18**

Appendix B: Identification of Local WEF Nexus Research "Champions"

South African based WEF nexus researchers were identified based on three criteria:

i. The first criterion included identifying researches that had one or more publications on a nexus-based approach, either as the first or co-author. This was done using Google Scholar, Web of Science and Scopus search engines, among others. Key search phrases that were used included 'water-energy-food nexus', 'water-land-energy nexus' and 'climate-land-energy-water nexus'. The search was not limited to journal publications but also included reports and popular articles. The search was filtered to show only those researchers whose affiliation included South Africa.

ii. The second criterion was related to identifying researchers who have presented at conferences and symposia on any of the nexus frameworks listed above. Similarly, the search was filtered to only identify those authors/presenters with an affiliation in South Africa.

iii. The third criterion was related to identifying researchers who have attended WEF nexus related events (workshops and symposia) held in South Africa. Some known events include Water Research Commission Dialogues, the Water Research Commission Biennial Water Symposium, and the jointly organised workshops between the WRC, UKZN's Centre for Water Resources Research and Future Earth. Stakeholders that have either participated or attended such events were also included.

It is hoped that by means of this three-pronged approach, the list of stakeholders includes the breadth of WEF nexus stakeholders in South Africa. There may be other WEF nexus stakeholders who have been excluded as they may not have published on the WEF, and/or presented or attended a conference or symposia related to the WEF Nexus. Thus, the list provided should be treated as a first draft that will need to undergo regular updating.

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