INTEGRATING WATER-ENERGY-FOOD NEXUS INNOVATIONS AND PRACTICES INTO POLICY, GOVERNANCE AND INSTITUTIONAL FRAMEWORKS FOR SUSTAINABLE DEVELOPMENT IN VHEMBE DISTRICT MUNICIPALITY, LIMPOPO PROVINCE, SOUTH AFRICA

Report to the
Water Research Commission

by

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WRC Report No. 3116/1/23
ISBN 978-0-6392-0589-2

March 2024

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The publication of this report emanates from a project entitled “Integrating water-energy-food nexus innovations and practices into policy, governance and institutional frameworks for sustainable development in Vhembe District Municipality, Limpopo Province, South Africa” (WRC Project No. C2020/2021-00392)

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

Introduction

The concept of Water-Energy-Food (WEF) nexus is critical in addressing the complex and interconnected challenges related to water, energy, and food resources. Agriculture is the largest consumer of freshwater, utilizing 70% of the world's withdrawals. This underlines the critical dependence of the agricultural sector on water resources. The energy sector, while not the largest consumer, still requires significant water withdrawals. Additionally, energy production and supply are crucial for all aspects of modern life, including agriculture. The world is facing the challenge of meeting the needs of a growing population (expected to reach 9.8 billion by 2050) while ensuring sustainable use of resources. Changes or challenges in one system can affect the others. For instance, water scarcity can impact agriculture and energy production. Similarly, energy is necessary for water supply and agricultural processes. Addressing these challenges requires an integrated approach that considers the nexus between water, energy, and food. It involves understanding the trade-offs and synergies between these sectors. Solutions need to be sustainable, considering the finite nature of natural resources and the challenges posed by climate change. Technology and policy decisions play a vital role in managing these interconnected systems. Innovations in agriculture, water conservation, renewable energy, and policy frameworks that encourage efficient resource use are crucial. Urban areas and industries are also increasing their demands on these resources, further emphasising the need for integrated and sustainable management. The WEF Nexus approach encourages holistic planning and decision-making. By understanding the interdependencies and potential conflicts between these sectors, policymakers and stakeholders can develop more resilient and sustainable strategies for the future. This approach aligns with the broader goals of united nations' sustainable development goals (SDGs), the Africa Union Agenda 2063 and the South Africa National Development Plan (NDP) 2030 vision, ensuring that economic growth, social equity, and environmental protection are all taken into account.

The study set out (i) to conduct context-specific literature search (i.e. desktop study) to expand knowledge base on WEF nexus and establish the current level of WEF nexus resource usage in the study area, (ii) to assess suitable WEF smart innovations and practices for the study area, (iii) to assess how the existing policy, governance and institutions systems affect implementation of the WEF nexus approaches at household level, and (iv) to develop or identify a framework for improving policy, governance and institutional structures in order to support effective implementation of WEF nexus innovations and practices at household level in the selected study area along the Nzhelele and Luvuvhu river catchment areas in Vhembe District Municipality (VDM) in Limpopo Province.

Research Methodology

The research methodology comprised of distinct but interrelated four work packages, which cover identifying WEF nexus innovations and practices and policy, governance and institutional frameworks. The first work package involved desktop study and selection of study communities and sectors in VDM. The desktop study involved an in-depth review of literature on research themes related to WEF nexus innovations and practices, policy, governance and institutional dimensions was carried out. The desktop study also involved a comprehensive review of scholarly articles and national and provincial reports and documents to identify relevant innovations and practices, policy, governance, and institutional settings for the WEF nexus approach. The desktop study also identified the communities' socio-economic context and general conditions in the study areas. The second work package involved selection of study communities and sectors in the study area. The third work package involved identifying and quantifying the WEF nexus smart technologies, innovations, and practices found in the study area. The work package also involved fieldwork, surveys and observations to collect water, energy and food resource data. The data was further analysed both inductively and deductively. The fourth work package involved assessment of current policy, governance and

institutional systems under which the communities operate, and examine how these systems affect the implementation of WEF nexus practices in the study area. This work package also development/selection of policy and governance frameworks for supporting implementation of WEF nexus practices.

Literature Review

A review was conducted on the body of literature that covers areas such as global perspectives of WEF nexus, the need for WEF nexus solutions, WEF nexus interlinkages and frameworks, the WEF nexus research in South Africa, WEF nexus innovations and practices, policy and governance and institutional dimensions of WEF nexus and the application of WEF nexus solutions at the household and community levels. The review findings show that there are various methods and approaches for conducting research on the WEF nexus approach. The current research benefited from the wide range of approaches and methods various researchers have used to study the WEF nexus approach. These approaches provided the basis for developing the methodology for the current study. The literature review findings also highlighted the need to understand the existing and potential WEF nexus innovations and practices applied at the household and community levels and how existing policies and governance systems affect the use and management of WEF resources at these levels.

Innovations and Practices

Innovations, technologies and practices, which are smart, play a critical role to address the water, energy and food challenges. The introduction of new and appropriate innovations and practices can improve resource efficiency in the water, energy, food sectors, and contribute to their security and sustainability. Climate Smart Agriculture (CSA) and food systems includes Conservation agriculture (CA), Precision Agriculture, Crop-livestock integration, One Health, Sustainable Intensification, Nature-based Solutions, rainwater harvesting, and Precision Agriculture amongst others; with smart-water approaches aim at developing alternative water sources as well as reducing losses through recycling and use of sensors to reduce wastage; and whilst Smart Energy Systems take an integrated holistic focus on diversification of energy sources in the energy mix (electricity, heating, cooling, industry, buildings, and transportation).

The study identified Smart WEF innovations, technologies and practices in VDM. There exist several innovations, technologies and practices across the WEF resource sectors with Indigenous Knowledge Systems (IKS) accounting for the majority of innovations and practices yet being accorded less attention. Mainstreaming IKS innovations and practices into the policy interventions could thus increase the suite of WEF smart innovations and practices and policy options for tackling the wicked sustainability challenges across scale. However, a life cycle assessment of particular innovations and practices may be required to quantify actual environmental footprints.

Policy, Governance and Institutional Dimensions

The study aimed to contribute to policy and decision-making processes, and support the adoption of nexus innovations and practices and enhance the sustainability and resource security of each component system in the Nzhelele and Luvuvhu river catchment areas of the VDM in the Limpopo Province of South Africa. The barriers and enablers to adoption identified here as well as policy and governance gaps identified will go along in pursuit of the nexus agenda. The interrelation of the nexus resources can be visualised from their importance, use and chain impact. To a greater extent, the communities are able to link the WEF resources and the chain impact. Several barriers at policy and informational levels as the socio-economic challenges such as poverty undermine the WEF nexus implementation. This will require collaborative institutional and governance approaches as the challenges are cross-cutting. In particular, knowledge, informational and financing barriers need to be accorded greater attention. The use of innovation platforms may greatly increase synergy. Innovation platforms are ways to bring together different stakeholders to identify solutions to common problems or

to achieve common goals. This is also to streamline the governance structures, and institutional arrangements in the planning implementation, monitoring and evaluation of WEF nexus problems and objectives.

The analysis of the degree of support of the legislation, policies, and strategies for the WEF nexus approach shows that the Constitution provides solid support for the WEF nexus approach. However, there is a complex collaboration between interconnected sectors, diverse sectoral institutional frameworks and insufficient governance frameworks that must be overcome to improve the WEF nexus approach at the sectoral level. Another challenge is a lack of incentive to collaborate with multiple stakeholders from many disciplines and sectors, and government levels. Some of the sectoral policies and strategies do explicitly support the WEF nexus approach in their design, implementation, and monitoring, evaluation and learning (MEL). These are challenges which must be overcome in order to achieve the best out of the nexus approach.

The study has identified two main areas which must be addressed. The first area is the apparent limited support offered by national legislation, policies, and strategies for the WEF nexus approach. There is more to be done to integrate WEF nexus principles in national and sectoral legislation, policies and strategies. The second area is that communities have limited knowledge and understanding of the nexus nature of the WEF resources they manage and utilise. Successful implementation of the WEF nexus approach at local and household levels depends on, among other things, the communities' understanding of the extricate connectivity and linkages of the WEF resources, and hence their understanding of the synergies and trade-offs that exist as they manage and use the resources. The results of the study show that there is more to be done to enhance communities' knowledge and understanding of these basic linkages among the WEF resources. In order to improve synergetic solutions between the systems in which resources and activities are arranged to provide final services for the community, communities need to be aware of the nexus perspective. Given the increasing understanding of the inter-connectedness between the systems, conventional perspectives dealing with the systems separately would not be seen as effective even from each system itself and the sustainability aspect of the community.

Policy Framework

The proposed policy framework for cross-sectoral coordination in planning and implementing the nexus approach is designed to address the interconnections and interdependencies between these sectors. It aims to provide a systematic approach to prioritize policy decisions, actions, and resource allocation across the WEF sectors, as well as foster collaboration among organizations. The framework consists of four key steps:

- *Harmonizing policy goals:* This step involves aligning the policy goals of the WEF sectors to ensure coherence and avoid conflicts. It requires identifying common objectives and areas of overlap among the sectors.
- *Identifying and mapping sectoral policy interactions:* In this step, the interactions between sectoral policies are identified and mapped. This includes understanding how policies in one sector can impact or be impacted by policies in another sector. The goal is to gain a holistic understanding of the interconnections and potential synergies or trade-offs.
- *Assessing compatibility with nexus objectives:* The compatibility of sectoral policies and strategies with nexus objectives is evaluated in this step. The focus is on identifying the extent to which sectoral policies contribute to or hinder the achievement of WEF nexus goals. This assessment helps prioritize policies and strategies that are in line with the overarching objectives of the nexus approach.
- *Identifying smart strategies for synergies:* The final step involves identifying smart strategies that can bring synergistic effects across the WEF sectors. This includes

exploring innovative approaches, technologies, and policies that can optimize resource use and enhance efficiency. The aim is to find strategies that maximize co-benefits and minimize trade-offs among the sectors.

Throughout the application of the framework, three broad criteria – synergies, trade-offs, and neutrality – are used to assess the impacts of policies and strategies. Synergies refer to the co-benefits that can be achieved by integrating efforts across sectors. Trade-offs represent the externalities or conflicts that may arise when pursuing goals in one sector at the expense of another. Neutrality refers to the avoidance of negative impacts or biases towards any particular sector.

To operationalize the framework, a common cross-sectoral coordination body is recommended. This coordination body would be responsible for implementing the four-step framework, facilitating consultation and dialogue among the sectors, and fostering consensus on prioritizing activities. The aim is to break down sector-specific silos and promote collaboration and alignment of policies and strategies. By adopting this framework and applying it rigorously, decision-makers can develop a long-term, concerted, and sustained strategy to achieve resource security and address the complex challenges at the WEF nexus.

Governance Framework

The proposed governance framework is designed to address the interrelated challenges of water, energy, and food (WEF) resource management. The framework aims to establish a set of governance functions and attributes that work together to achieve specific outcomes related to WEF resources. It emphasizes the importance of understanding how different functions and attributes are linked, how institutions can self-assess their weaknesses in relation to the framework, and how the framework can be used to design better governance interventions. The framework's key components are:

Governance Functions: These are the essential elements and processes that need to be in place to develop and manage WEF resources and services effectively. The functions encompass various aspects of resource management, ensuring coordination and alignment between them.

Governance Attributes: These attributes are related to how the governance functions are implemented. They shape how the functions are carried out and influence the outcomes of the governance process. Attributes could include factors such as transparency, inclusivity, accountability, adaptability, and stakeholder engagement.

Interrelation: The framework emphasizes the interrelation between the governance functions and attributes. The successful achievement of desired outcomes depends on the effective coordination and alignment of both functions and attributes.

Stakeholder Values and Aspirations: The governance of WEF resources is not a standalone process but is influenced by the values and aspirations of the stakeholders involved. Their input and participation play a crucial role in shaping the governance approach.

The potential contributions of this framework are threefold:

a) Improved Understanding: The framework can be used to understand how different functions and attributes are linked and how they can lead to desired outcomes. By analysing and applying the framework at national and local levels, practitioners can gain insights into WEF governance practices.
b) Institutional Self-Assessment: Institutions can use the framework to identify their opportunities, strengths, weaknesses, and threats in relation to WEF governance. This self-assessment can reveal common trends across various institutions.
c) Better Governance Intervention Design: A deeper understanding of the WEF governance pathway can lead to the design of more effective governance

interventions. By leveraging the framework, policymakers and practitioners can improve their decision-making processes and outcomes.

The next steps for using the framework are:

Detailed Operational Activities: To enhance the assessment of governance, the framework can be further refined by specifying operational activities (sub-functions) within and between the core functions. This level of detail allows for better adaptability to different contexts.

Practical Guidance: Develop practical guidance on how to apply specific attributes when performing WEF governance functions. Practical guidance can help stakeholders implement the framework effectively.

Focus on Values and Behaviours: Understand how working with values and behaviours can lead to improved governance outcomes. This could involve promoting positive behaviours and aligning stakeholder values with the desired outcomes of WEF governance.

Overall, the framework provides a comprehensive approach to addressing the challenges of WEF resource management and offers a structured methodology for assessing and improving governance practices in this context. It is recommended that future research work be conducted which will use the framework to assess the performance of governance systems and identify specific governance gaps which need to be addressed.

Capacity Building

The project resulted in the development and enhancement of institutional and human capacities. The human capacities related to formal training of students and enhancing capacities of communities in implementing WEF nexus practices. The project initially recruited three full-time students who were conducting their MSc research projects on the WEF Nexus Project as part of capacity building. Communities which participated in the study included Siloam, Phadzima, Khalavha, Sambandou and Malavuwe which are within Vhembe District Municipality. Communities gained knowledge on the concept of WEF nexus and how it can benefit, technological innovations and practices (some of which they were already implementing but without realising that they fit with the WEF nexus).

The capacity of the partner institutions was enhanced through the implementation of the project. Institutional arrangements. The partner institutions were CLOVITA Consulting Services, OZONE Agric Development Solutions, and the University of Venda. The participating institutions shared knowledge on research methodologies and data analysis techniques. The research team also learned a lot about indigenous knowledge systems related to WEF nexus which communities shared.

The project has helped to build capacities of students in terms of conducting research and disseminating research findings to various audiences. The capacity of participating communities and the research partner institutions were enhanced through the implementation of the project. The partner institutions benefited from sharing research methodologies and data analysis techniques, as well as dissemination of the research findings. The research teams also benefited from the vast experience of indigenous knowledge systems on WEF nexus practices by the participating communities and households. Participating communities and households benefited from the new knowledge on the linkages among the WEF resources which they use, as well as sharing indigenous knowledge systems among them. Knowledge dissemination was done through presentation at symposium and publication of articles in journals.

Innovation Report

The study has identified several innovations and practices across the WEF resource sectors.

Indigenous knowledge system account for the majority of the innovations and practices in the study. However, the IKS require great attention in order for the communities to benefit from them. Hence, mainstreaming IKS innovations and practices into the policy interventions could thus increase the suite of WEF smart innovations and practices and policy options for tackling sustainability challenges across scales. There are various smart innovations for managing and utilizing water, energy, and food/agricultural resources. The greater impact of these innovations lies in scaling out which is about impacting greater numbers through replication and dissemination, increasing the number of people or communities impacted, scaling up to change the rules of the game, and in scaling deep which relates to the notion that durable change has been achieved only when people's hearts and minds, their values and cultural practices, and the quality of relationships they have, are transformed.

The study has developed policy and governance frameworks and are innovative tools for assessing policy and governance relevance for supporting WEF nexus practices in the country. The value of these innovative frameworks lies in operationalizing them as successful implementation of the WEF nexus approach at local and household levels depend on, among other things, the existence of enabling environment provide by good policy and governance systems.

Key Recommendations

A holistic water, energy and food security system requires a detailed life cycle assessment evaluation impact assessment of the available suit of WEF innovations and practices alongside an assessment of policy and governance framework impacting them to evaluate the smartness of such innovations and thus inform policy on appropriate WEF smart interventions.

The innovations, technologies and practices found to be working within the local context and are promising should be taken to scale. The greater impact can be achieved through:

- "Scaling out", which is about impacting greater numbers through replication and dissemination, increasing the number of people or communities impacted.
- Changing institutions, policy and law – "scaling up" to change the "rules of the game".
- Strategies for "scaling deep" related to the notion that durable change has been achieved only when people's hearts and minds, their values and cultural practices, and the quality of relationships they have, are transformed.

The following recommendations were made based on the results of the study:

- Conduct transdisciplinary research to test and validate the promising WEF nexus innovations, technologies and practices using co-creation approaches (including IKS);
- Integrate WEF nexus in national and sectoral legislation, policies and strategies to enhance the support of these to the implementation of the WEF nexus approach in communities;
- Support multi-stakeholder forums to operationalise a sector-wide approach to addressing the barriers and creating an enabling environment for WEF coordination and adoption, especially with respect to financing, addressing policy bottlenecks and information dissemination and smart WEF technology diffusion;
- Strengthen multi-level and cross-level WEF coordination mechanisms;
- Review of institutional frameworks to align itself with the WEF agenda and cross-cutting issues such as financing;
- Strengthening WEF nexus policies, strategies and regulations, implementation, monitoring and evaluation;
- Improve the coordination of multilevel and cross-level actors;
- Enhance the effectiveness of communication channels (electronic, digital and print as well as social media) to enhance their impact on knowledge dissemination and address the weakness in extension and advisory services;

- Explore innovation platforms as vehicles for dissemination, innovation, and extension and advisory service delivery;
- Conduct public information and awareness campaigns on sustainable WEF innovations and practices; and
- Engage in policy advocacy on existing WEF policies, strategies and regulations and their enforcement.

It is recommended that the next steps for using the governance framework are to: (i) further detail operational activities (sub-functions) within and between the core functions, which can allow for more detail in the assessment of governance, as well as for adaptability to different contexts; (ii) to develop practical guidance for how to apply certain attributes when performing WEF governance functions; and (iii) to understand better how working with values and behaviours can improve governance outcomes.

The results of the analysis of degree of support of the legislation, policies, and strategies for the WEF nexus approach show that the complex collaboration between interconnected sectors, diverse sectoral institutional frameworks and interests, insufficient governance frameworks, and a lack of incentive to collaborate with multiple stakeholders from many disciplines and government levels are some of the challenges that must be overcome in order to improve WEF nexus approach. Some of the sectoral policies and strategies do not explicitly support the WEF nexus approach in their design and implementation.

The proposed policy framework for cross-sectoral coordination in planning and implementing the water-energy-food (WEF) nexus approach is designed to address the interconnections and interdependencies between these sectors. It aims to provide a systematic approach to prioritize policy decisions, actions, and resource allocation across the WEF sectors, as well as foster collaboration within organizations. The framework consists of four key steps namely harmonizing policy goals, identifying and mapping sectoral policy interactions, assessing compatibility with nexus objectives, and identifying smart strategies for synergies. Throughout the application of the framework, three broad criteria – synergies, trade-offs, and neutrality – are used to assess the impacts of policies and strategies. Synergies refer to the co-benefits that can be achieved by integrating efforts across sectors. Trade-offs represent the externalities or conflicts that may arise when pursuing goals in one sector at the expense of another. Neutrality refers to the avoidance of negative impacts or biases towards any particular sector.

To operationalize the framework, a common cross-sectoral coordination body is recommended. This coordination body would be responsible for implementing the four-step framework, facilitating consultation and dialogue among the sectors, and fostering consensus on prioritizing activities. The aim is to break down sector-specific silos and promote collaboration and alignment of policies and strategies. By adopting this framework and applying it rigorously, decision-makers can develop a long-term, concerted, and sustained strategy to achieve resource security and address the complex challenges at the water-energy-food nexus.

The findings of the study suggest that success in implementation WEF nexus-relevant policies depends on the extent to which not just individual policy-makers but also relevant institutions and agencies covering the critical sectors have opportunities for collaboration and involvement in the policy reform. This requires setting up partnerships and/or collaborative agreements with institutions and agencies involved in policy and decision-making to create a basis for shaping the focus of the WEF nexus practices and for the successful and effective uptake of such practices.

The study has shown that there is need for future research work to assess how best to mainstream IKS innovations and practices into the policy interventions which could increase

the suite of WEF smart innovations and practices and policy options for tackling the wicked sustainability challenges across scale. There is also need for future research work to be conducted which will use the proposed governance framework to assess the performance of governance systems and identify specific governance gaps which need to be addressed.

ACKNOWLEDGEMENTS

The team thanks the following Reference Group Members for guidance and advice throughout the project:

Prof N.S. Mpandeli	:	Water Research Commission
Dr L. Nhamo	:	Water Research Commission
Dr S.N. Hlophe-Ginindza	:	Water Research Commission
Ms M. Kapari	:	Water Research Commission
Dr A. Senzanje	:	University of KwaZulu-Natal
Prof S. Walker	:	Agricultural Research Council
Dr I. Jacobs-Mata	:	International Water Management Institute
Dr T. Chibarabada	:	Zimbabwe Sugar Association
Ms P. Mukuyu	:	International Water Management Institute

In terms of capacity building, three Master's students participated in the project. The team would like to acknowledge communities, officials and institutions that supported the project in various ways. These are:

Villages

- Phadzima
- Sambandou
- Tshakhuma
- Siloam
- Malavuwe
- Khalavha

Chiefs

- Chief Radzilani Ntakuseni Onesimas Zwokundavhalala (Phadzima Vhulaudzi)
- Chief Mugwena Mashudu Justice (Siloam)
- Chief Tshivhase Mushe Moses (Khalavha)

Ward Councillors and members

- Councillor Mukheli Khuliso (Siloam)
- Councillor Maduse Livhuwani Sathiel (Khalavha)
- Nemukula Livhuwani Nelson (Ward secretary, Sambandou)
- Tshamano Mbulaheni (Right hand man Phadzima)

Key Informants Interviews (KII)

- Vhembe Department of Agriculture and Forestry
- Department of Water and Sanitation
- Eskom
- Univen FM
- Phalaphala FM

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AFOLU	Agriculture, Forestry and Land Use
CA	Conservation Agriculture
CBO	Community-based Organization
CCAFS	Climate Change, Agriculture and Food Security
CMAs	Catchment Management Agencies
CSA	Climate-smart agriculture
CSO	Civil Society Organization
DALRRD	Department of Agriculture, Land Reform and Rural Development
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DoE	Department of Energy
DPE	Department of Public Enterprise
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EM	Effective Microorganisms
FAO	Food and Agriculture Organization
FGDs	Focus Group Discussions
FOG	Fats, Oils, and Grease
GHG	Greenhouse Gas
HH	Household
IBs	Irrigation Boards
ICT	Information and Communication Technology
IFPRI	International Food Policy Research Institute
IKS	Indigenous Knowledge System
IPPs	Independent Power Producers
IPs	Innovation Platforms
IT	Information Technology
IWRM	Integrated Water Resource Management
KIIs	Key Informant Interviews
MDGs	Millennium Development Goals
MLG	Multi-level Governance
NDP	National Development Plan
NEMA	National Environment Management Authority
NERSA	National Energy Regulator of South Africa
NGO	Non-Governmental Organization
NSA	Nutrition-sensitive Agriculture
NWRS	National Water Resource Strategy
OECD	Organisation for Economic Co-operation and Development
PA	Precision Agriculture
SACCO	Credit Cooperative Organization
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SNA	Social Network Analysis
SPICE	Solar Pump Irrigators' Cooperative
TERI	The Energy and Resources Institute

TV	Television
TVET	Technical and Vocational Education and Training
VDM	Vhembe District Municipality
WCED	World Commission on Environment and Development
WEF	Water-Energy-Food
WHO	World Health Organisation
WMA	Water Management Area
WRC	Water Research Commission
WUAs	Water Users Associations

1 CHAPTER 1: GENERAL INTRODUCTION

1.1 Background

Water, energy and food security as basic needs have been crucial issues in human history dating back to the earliest days of civilization (Kim et al., 2015). Global human society must now attempt to solve a set of complex and interrelated problems that Diamond (2005) characterises as “fundamental threats to human civilisation”. Many of these issues are directly related to the areas of water, energy and food (WEF) production, distribution, and use, especially in developing countries. Water is used for extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing feedstock for biofuels and for generating electricity. Conversely, energy is needed for extracting, transporting, distributing and treating water. Additionally, energy fuels land preparation, fertilizer production, irrigation and the sowing, harvesting and transportation of crops. Food production further impacts the water sector through land degradation, changes in runoff, disruption of groundwater discharge, water quality and availability of water and land for other purposes such as natural habitat. The increased yields that have resulted from mechanization and other modern measures have come at a high energy price. Reducing both the impacts and drivers of climate change will require major shifts in the way we use and reuse the South Africa’s limited water resources. Even though often overlooked, water resources are essential part of solution to climate change.

A number of studies have been conducted to assess application of the WEF nexus approach in South Africa. Mabhaudhi et al. (2018a) conducted a study in which they reviewed available information and knowledge about the WEF nexus in South Africa, and they conducted 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. Seeliger et al. (2018) conducted a study in which they applied the water-energy-food nexus to farm profitability in the Middle Breede Catchment, South Africa, and they demonstrated how the WEF nexus approach can provide insights into how integrated water management can be applied in a particular agricultural context. Mabhaudhi et al. (2019), in their study, argued that better understanding of the policy and institutional dimensions at household scale is important for the nexus approach to have greater impact. According to the study of Nhamo et al. (2020), who developed an integrative analytical model for the WEF nexus and applied it to assess progress towards the Sustainable Development Goals (SDGs) in South Africa, the country’s management of the nexus resources is marginally sustainable. To date, nexus framings and applications of the nexus approach have tended towards technical assessments to enhance productivity, optimise synergies and identify trade-offs across nexus sectors to inform natural resource governance (Howells et al., 2013). However, resource ‘security’ is not solely driven by availability of the resources but also by access to resources, the capacity to utilise resources as well as dynamics of social power relations and the strength of institutions (Ericksen, 2008; Pritchard et al., 2013). Various studies have shown that ineffective policies, governance and institutional arrangements are some of the main factors that limit access to and sustainable use of water, energy and land resources at household level (Denison et al., 2016).

The assessment of implementing the WEF nexus innovations and practices at household level can be considered through its link to the livelihoods of the people. According to Biggs et al. (2015), the framework consists of internal factors (livelihoods, water, energy and food) which are influenced by external factors (hazards, economic growth and pressure, and institutions and policies). In this study, we focused on the influence of the external factors of policy, governance and institutions on implementation of WEF nexus approach at household level.

The study examined WEF nexus innovations and practices to provide the necessary foundation for policy, governance and institutional systems of an integrated nexus approach

with a focus on the inter-dependencies between water, energy and food systems, which are essential elements for management and policy-making. The advantage of such an integrated approach is that it provides policy and decision makers with the necessary information and analyses of innovations and practices needed to achieve the goals and targets in a balanced and integrated manner in all three dimensions of sustainable development (economic, social and environmental). Hence, this study will contribute to the understanding of the policy, governance and institutional dimension of the water-energy-food nexus, and address the institutional arrangements for adopting more nexus-based solutions in the water, energy and food systems at household level.

The study identified WEF nexus innovations and practices necessary to provide nexus-based sustainable development solutions at household level thereby empowering communities to effectively use nexus resources. The study moved the water-energy-food nexus construct beyond an input-output relationship into the realm of resource governance, policy, and adaptation. In this way, the study will also contribute to policy and decision-making processes that will support the adoption of nexus innovations and practices and enhance sustainability and resource security of each component system in the Vhembe District.

1.2 Research aim and objectives

The main purpose of the study is to identify WEF nexus innovations and practices necessary to provide nexus-based sustainable development solutions at household level thereby empowering communities to effectively use nexus resources and to contribute to policy, governance, institutional and decision-making processes that will support the adoption of nexus innovations and practices and enhance sustainability and resource security of each component system in the Vhembe District.

The specific objectives of the study were:

1) To conduct context-specific literature search (i.e. desktop study) to expand knowledge base on WEF nexus and establish the current level of WEF nexus resource usage in the study area;
2) To assess suitable WEF smart innovations and practices for the study area;
3) To assess how the existing policy, governance and institutions systems affect implementation of the WEF nexus approaches at household level; and
4) To develop or identify a framework for improving policy, governance and institutional structures in order to support effective implementation of WEF nexus innovations and practices at household level in the study area

1.3 Scope of the project

The scope of the study involved identifying smart innovations and practices as well as factors influencing their adoption to inform policy and decision-making processes to support scaling up the adoption of innovations and practices that enhance sustainability and resource security in support of the SDGs. The study also investigated the current policy, governance and institutional systems under which the communities utilise and manage water, energy and food (WEF) resources in Vhembe District Municipality (VDM), Limpopo Province, South Africa. Field work was conducted during which semi-structured interviews and key informant interviews (KII) were conducted supplemented with observational checklists. These were carried out to identify the WEF nexus smart technologies, innovations, and practices in Nzhelele and Luvuvhu river catchment areas of VDM, Limpopo Province, South Africa. This involved conducting an extensive desktop review of relevant documents and reports on policies, regulations, governance, and institutions that are related to the WEF nexus in South Africa. The study identified WEF nexus innovations, technologies and practices were identified as well as indigenous knowledge. The study also involved developing policy and governance frameworks as tools for assessing policy and governance dimensions of implementing WEF nexus practices at household and community levels.

1.4 Study limitations

At the beginning of the year, two students withdrew from the project due to their inability to register in time for them to be funded by Water Research Commission (WRC) bursaries. This created a gap in the capacity-building process. However, the project was able to recruit replacement students in time to qualify for the WRC bursaries.

The other challenge the project faced included delays in getting the participation of community members and other stakeholders in the data collection processes. These delays were partly due to COVID-19 restrictions. Due to COVID-19 limitations, the Research Team continued to conduct all project meetings using virtual platforms. Electronic meetings greatly increase the ease with which we as a group were able to meet. However, there were some challenges we faced with this way of conducting meetings. There were cases where some team members had problems with internet connection due to poor network system and load shedding. The lifting of COVID-19 restrictions allowed the Research Team to carry out field activities effectively.

The other challenge is that virtual meetings do not allow increased information exchange. People meeting face-to-face communicate with each other in many ways that are not limited to voice. Facial expressions and body language convey a great deal of information, and unconscious communication cues help to facilitate discussion. These cues are often missed or lost entirely when a meeting is held virtually, decreasing the energy of participants. We missed the strong social factors which are in place during face-to-face meetings, requiring everyone to remain engaged with the meeting and to give their attention to the speakers. The other challenge with virtual meetings is that the urge for attendees to check emails or pour another cup of coffee is often tempting and leads to people not paying attention to parts of the meeting[1].

1.5 Structure of the report

This final report follows the WRC format for final report; hence, the structure of the report is laid out in line with the recommended WRC format. The first chapter lays out the context of the problem at hand, which is basically to understand and operationalise the WEF nexus innovations and practices and understand how policy, governance and institutional system affect implementation of the WEF nexus practices particularly at household level in South Africa. The chapter sets out the research aim and objectives as well as limitations which were encountered during the research work.

Chapter 2 gives a broad overview of the literature reviewed on existing knowledge on WEF nexus innovations and practices, policy and institutional frameworks as they relate to management and utilisation of WEF resources. The literature review covered what is known on the current research topic, how well this knowledge is established and where future research might best be directed. Hence, the literature review provided the foundation of knowledge on the topic related to WEF nexus innovations and practices and on how policy and governance systems affect the implementation of WEF nexus solutions.

Chapter 3 provides an outline of the general research methodologies applied in the research project in terms of study location, target population, sampling system, data collection instruments, and data analysis.

Chapter 4 presents an assessment and mapping of WEF nexus innovations and practices identified in VDM, Limpopo Province. The chapter presents smart water, energy and food/agricultural innovations and practices, as well as indigenous knowledge systems.

1 https://smallbusiness.chron.com/disadvantages-online-meetings-73892.html

Chapter 5 deals with roles of legislation, policy, governance and institutional systems in the implementation of the WEF nexus approach in the study area.

Chapter 6 covers the proposed policy, and governance and institutional frameworks for the implementation of WEF nexus approaches.

Chapter 7 is about integrating the WEF nexus into policy, governance systems, and decision making. The chapter also presents challenges and opportunities in integrating policies, and governance systems in effective implementation of the WEF nexus solutions and required capacity development and knowledge dissemination.

The last chapter, Chapter 8, summarises and concludes the report and provides recommendations going forward with regard to the WEF nexus innovation and practices, and policy and governance systems for supporting WEF nexus practices.

2 CHAPTER 2: REVIEW OF LITERATURE ON THE WEF NEXUS

2.1 Introduction

The review was conducted to examine existing body of knowledge on WEF nexus innovations and practices, policy and institutional frameworks as they relate to management and utilisation of WEF resources. The review's main focus was on the implementation of WEF nexus approach by communities in rural and peri-urban settings. The literature review covered areas such as global perspectives of WEF nexus, the need for WEF nexus solutions, WEF nexus interlinkages and frameworks, the WEF nexus research in South Africa, WEF nexus innovations and practices, policy and governance dimensions of WEF nexus, and the application of WEF nexus innovations and practices at the household and community levels.

2.2 Purpose and objectives of the review

The purpose of the literature review was to determine what is known on the current research topic, how well this knowledge is established and where future research might best be directed. Hence, the literature review was conducted to provide the foundation of knowledge on the topic related to WEF nexus innovations and practices and on how policy and governance systems affect the implementation of WEF nexus solutions.

The objectives of the literature review were to:

1) Identify areas of prior scholarship to prevent duplication and give credit to other researchers;
2) Identify inconstancies: gaps in research, conflicts in previous studies, open questions left from other researchers;
3) Identify the need for additional research and hence justifying the current research;
4) Identify the relationship of works in the context of its contribution to the current research topic and to other works; and
5) Place the current research within the context of existing literature, making a case for why further study is needed.

2.3 Scope of the review

The review was on the literature on WEF nexus innovations, technologies and practices, and on policy, institutional and governance dimensions of WEF nexus. There are a large number of studies on general aspects of the WEF nexus. However, since the focus of this research is on WEF nexus innovations, technologies and practices, governance and institutional frameworks, these general aspects will not be reviewed in detail and will only be referred to as appropriate.

2.4 Literature search strategy

2.4.1 Search engines

Google Scholar and electronic archives, including the WRC Knowledge Hub, were searched for publicly available reports on the water-energy-food nexus. Literature searches were also carried out in the indexed database Scopus©. Word clouds were used as indicators of search content summaries. Two searches on Scopus© were carried out. The first search had search words of: ("Water-energy-food" OR “WEF” AND "South Africa" AND (Limit-To (Language, “English”)), and it yielded 32 articles from 2003 to 2022. The second search had search words of: ("Water-energy-food" OR "WEF" OR "water policy" OR "water governance" AND "South Africa" AND (Limit-To (Language, “English”)), and it yielded 260 articles from 1996 to 2022.

2.4.2 Bibliometric analysis

These terms were used to facilitate the search, and inclusion/exclusion criteria were used to screen the articles that were found online. A number of articles were downloaded and those that met the screening criteria were then used in the analysis. In addition, the reference sections of the reviewed literature were examined for other relevant literature for inclusion.

The first search for article titles, abstracts, keywords was conducted with search words: ("Water-energy-food" OR “WEF” AND "South Africa" AND (Limit-To (Language, “English”)). Thirty-two (32) results came out from 2003 to 2022. The results are presented in Figure 2.1.

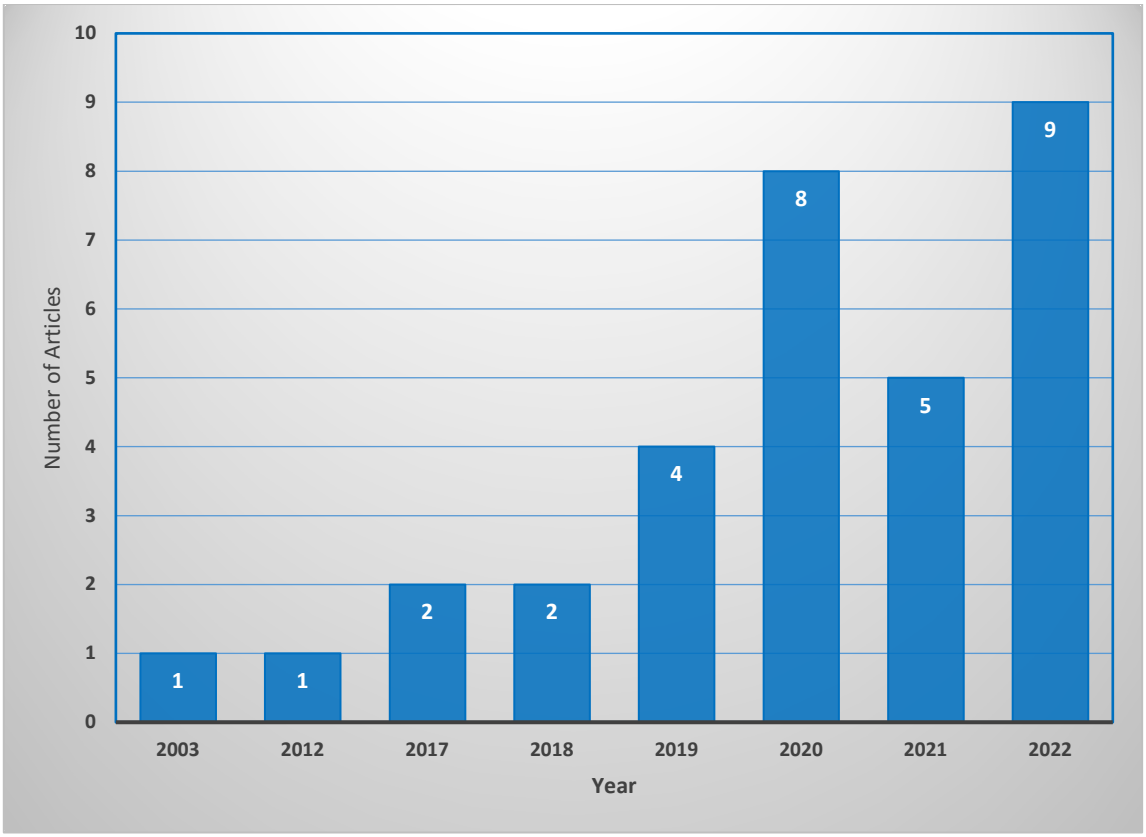


Figure 2.1: Bibliometric analysis output of the first search

The output of the document type for the first search is given in Table 1.

Table 2.1: Output of the document type for the first search

Document type	**Number**
Article	17
Book Chapter	6
Review	5
Conference Paper	3
Conference Review	1

The second search for article titles, abstracts, keywords was conducted with search words: **(**"Water-energy-food" OR "WEF" OR "water policy" OR "water governance" AND "South Africa" AND (Limit-To (Language, “English”)). Two hundred and seventy (270) results came out from 1996 to 2022. The results are presented in Figure 2.2.

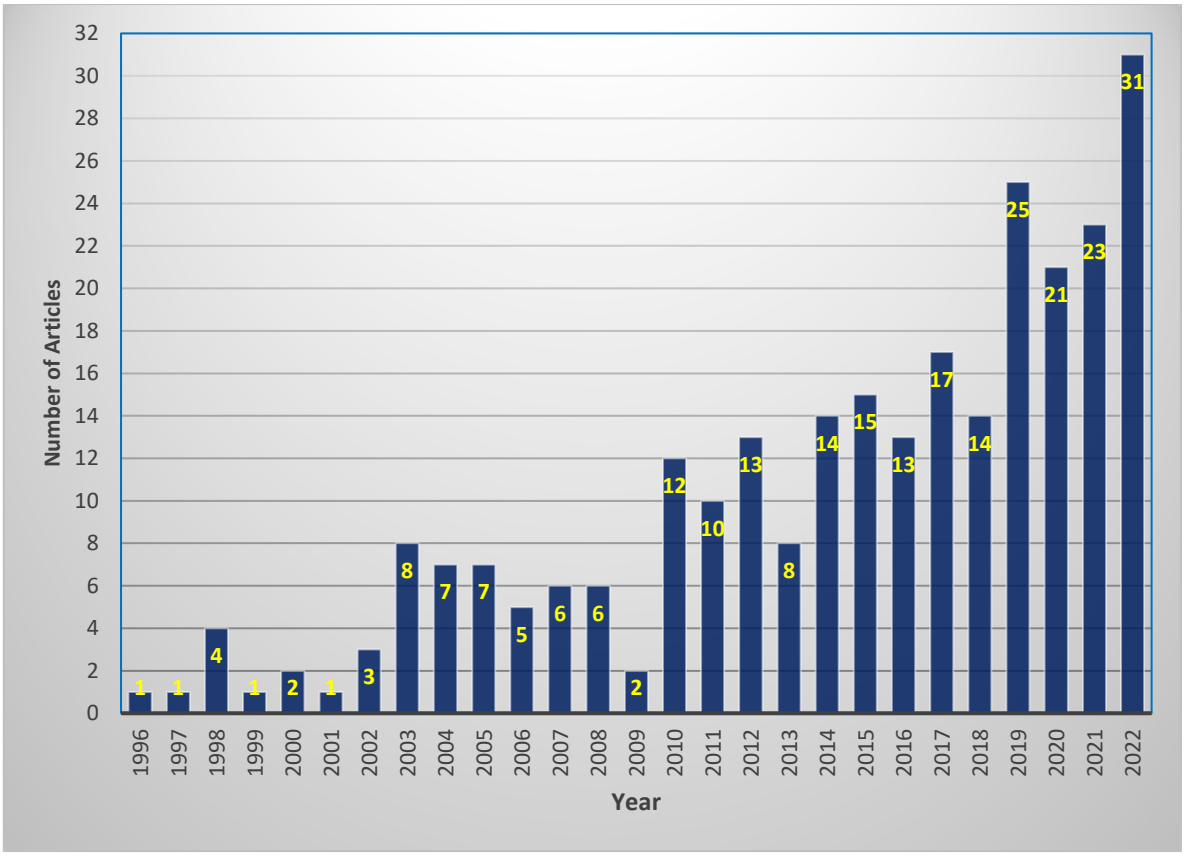


Figure 2.2: Bibliometric analysis output of the second search

The output of the document type for the second search is given in Table 2.2.

Table 2.2: Output of the document type for the second search

Document type	Number
Article	192
Book Chapter	33
Review	23
Conference Paper	9
Book	8
Editorial	3
Conference Review	1
Short Survey	1

2.4.3 Word cloud of keywords

A word cloud of keywords was used to improve the systematic feature of the literature review. A 'word cloud' is a visual representation of word frequency, the more commonly the term appears within the text being analysed, the larger the word appears in the image generated (Gottron, 2009). Word clouds are increasingly being employed as a simple tool to identify the focus of written material (Ennis, 2010). In this case, the word cloud analysis was used to give a visual impression of priority given to the literature research of direct relevance to WEF nexus

and related issues in South Africa. The word cloud shown in Figure 2.3 shows the most popular words used in the literature search for this study.

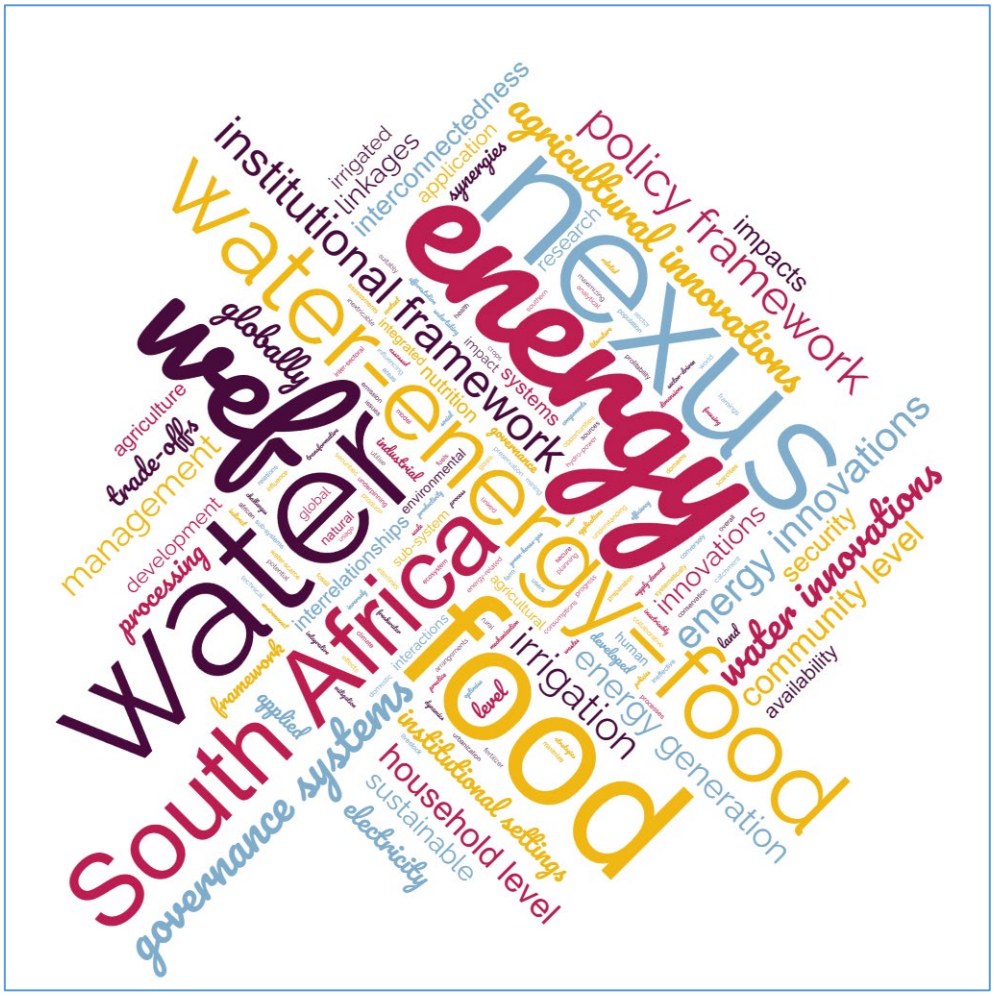


Figure 2.3: The word cloud of keywords for the literature review search

The output of the frequency analysis of the cloud is presented in Figure 2.4. The frequency and hierarchy followed the occurrences of the words: “water”, “energy”, “nexus”, “food”, “wef”, “South Africa”, “water-energy-food”, “governance systems”, “institutional framework”, “policy framework”, “energy innovations”, “agricultural innovations”, and “water innovations”.

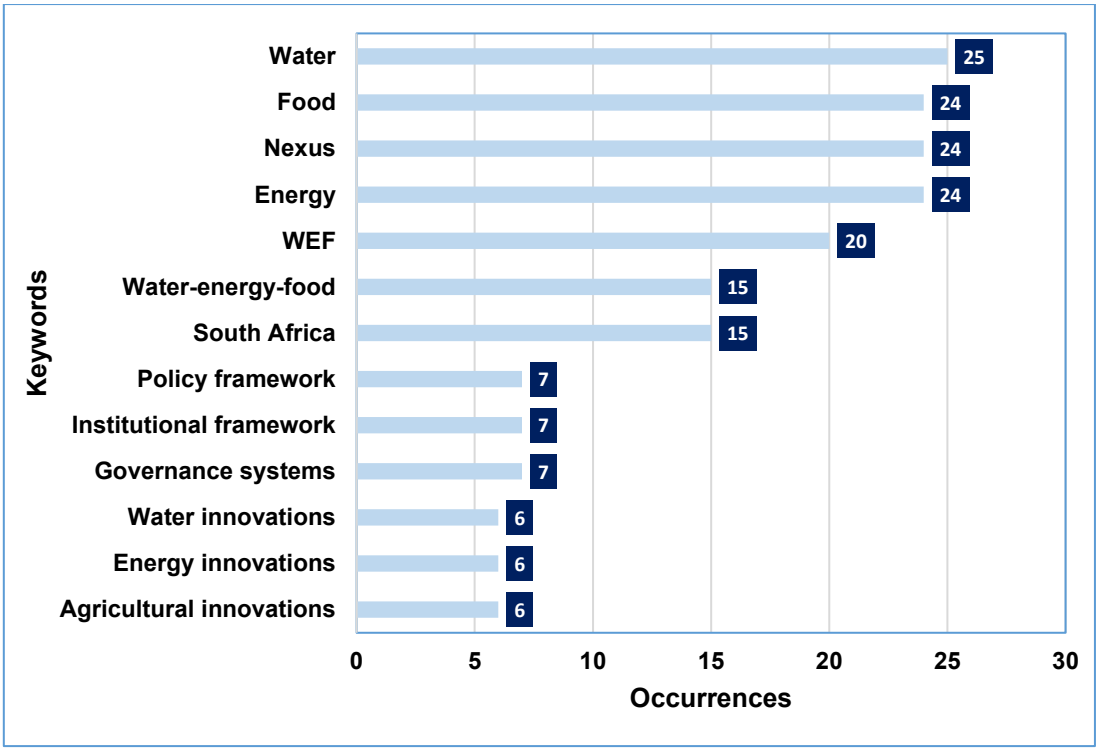


Figure 2.4: The words which occurred with the highest frequency in the dataset

2.5 Global perspectives of the WEF nexus

2.5.1 WEF resources under pressure

Agriculture accounts for about 70% of global water withdrawal (FAO, 2012). Roughly 75% of all industrial water withdrawals are used for energy production (WWAP, 2014). The food production and supply chain account for about 30% of total global energy consumption (WWAP, 2012) and 90% of global power generation is water-intensive (WWAP, 2014). It is reported that global water demand (in terms of water withdrawals) is projected to increase by 55% by 2050, mainly because of growing demands from manufacturing (400% increase) (WWAP, 2014). More than 40% of the global population is projected to live in areas of severe water stress by 2050 (WWAP, 2014). By 2035, water withdrawals for energy production could increase by 20% and consumption by 85% (WWAP, 2014). These projections indicate that the demand for food, water, and energy is growing steadily, but the resources required to generate them are limited and, in many cases dwindling (State of the Planet Declaration, 2012).

2.5.2 WEF nexus: interlinking actions

The interdependencies among water, energy, and food are numerous and multidimensional, and their relationship is often called the food, water, and energy nexus (Rasul and Sharma, 2016). Figure 2.5 presents the WEF nexus interlinkages. One of the important interfaces in this nexus is that water plays a vital role in food and energy production and sustains the ecosystems that support agriculture and other economic activities that are critical for achieving food and nutrition security. The second important interface is that energy is required for food production (especially irrigation) and water supply, including the extraction, purification, and distribution of water. Food production as a consumer of land, energy, and water is the third interface in the nexus. Agriculture, responsible for growing food, is a major user of water (more than 70% of all water use globally) and energy (Rasul and Sharma, 2016). Agriculture and food production further affect the water sector through land degradation, changes in runoff, and disruption of groundwater discharge. Sustainable agricultural practices, such as those designed to prevent land degradation, save water and energy by increasing water storage in the soil and groundwater recharge and by reducing the use of energy-intensive fertilizers.

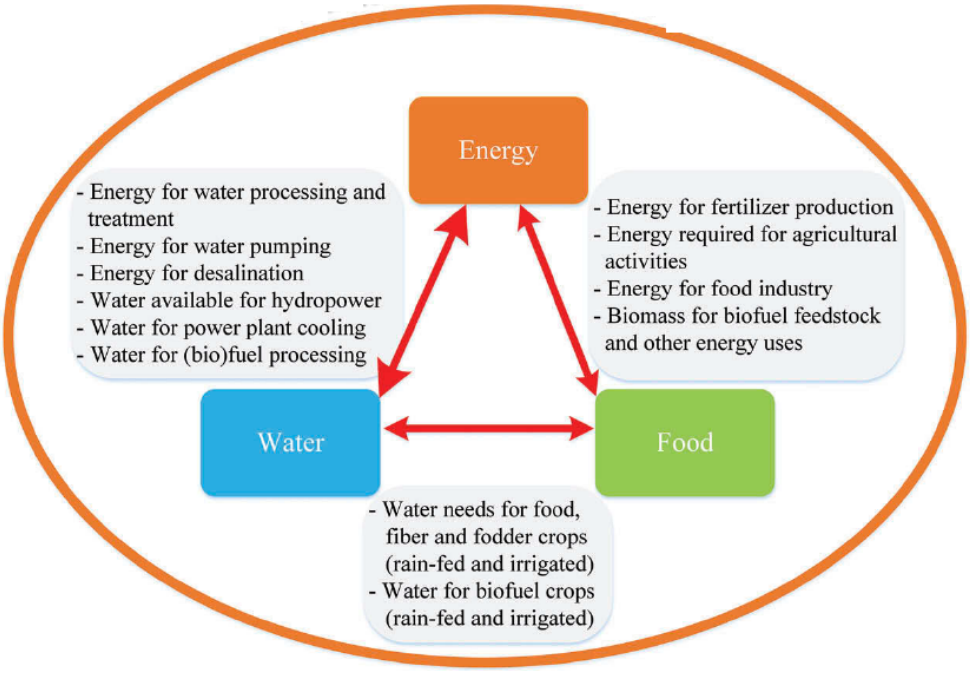


Figure 2.5: The WEF inter-linkages
(Source: Liu et al., 2017)

The nexus approach aims to systematize the interconnections and provide tools to assess the use of all resources. It is a system-wide approach, and recognizes the inherent interdependencies of the food, water, and energy sectors for resource use, seeks to optimize trade-offs and synergies, and recognizes social and environmental consequences. Understanding the linkages within the food, energy, and water nexus can provide opportunities to increase resource use efficiency and enhance cooperation and policy coherence among the three sectors (Rasul and Sharma, 2016).

In order to advance the notion of the WEF nexus, a number of global and regional conferences, workshops and meetings were held in 2011-2012, during the preparation phase for Rio+20 in June 2012 (Bizikova et al., 2013). Conferences and workshops that focused on elements of the WEF nexus at the global level included: 6th World Water Forum, Bonn 2011 Nexus Conference, World Congress on Water, Climate and Energy, and Water-Energy-Food Security: New Challenges and New Solutions for Water Management (Bizikova et al., 2013). At the regional level, gatherings include the Mekong and Rio International Conference on Transboundary River Basin Management; Asian Irrigation Forum; South African Water, Energy and Food Forum: Managing the Mega-Nexus; and 10th Gulf Water Conference in Doha. The key focus of these initiatives was to promote the WEF nexus by raising awareness, emphasizing the urgency of challenges related to WEF, providing forums for international dialogue, and suggesting policy and investment recommendations.

2.5.3 WEF nexus frameworks

Since the issue of WEF nexus became a global concern, a number of frameworks that define the relationships between the WEF elements and the character of potential responses within the WEF nexus have been developed. These include those by Hoff (2011) (Fig. 2.6) and Rasul (2014). In addition, many of the current frameworks have been developed by academic institutions such as the Stockholm Environment Institute (SEI); International Food Policy Research Institute (IFPRI); University of Pennsylvania; University of Montreal; Stockholm International Water Institute (SIWI) and The Energy and Resources Institute (TERI); international organizations, including United Nations agencies, the World Bank and

Organisation for Economic Co-operation and Development (OECD); World Economic Forum; and private entities such as the Swiss Reinsurance Company (Bizikova et al., 2013).

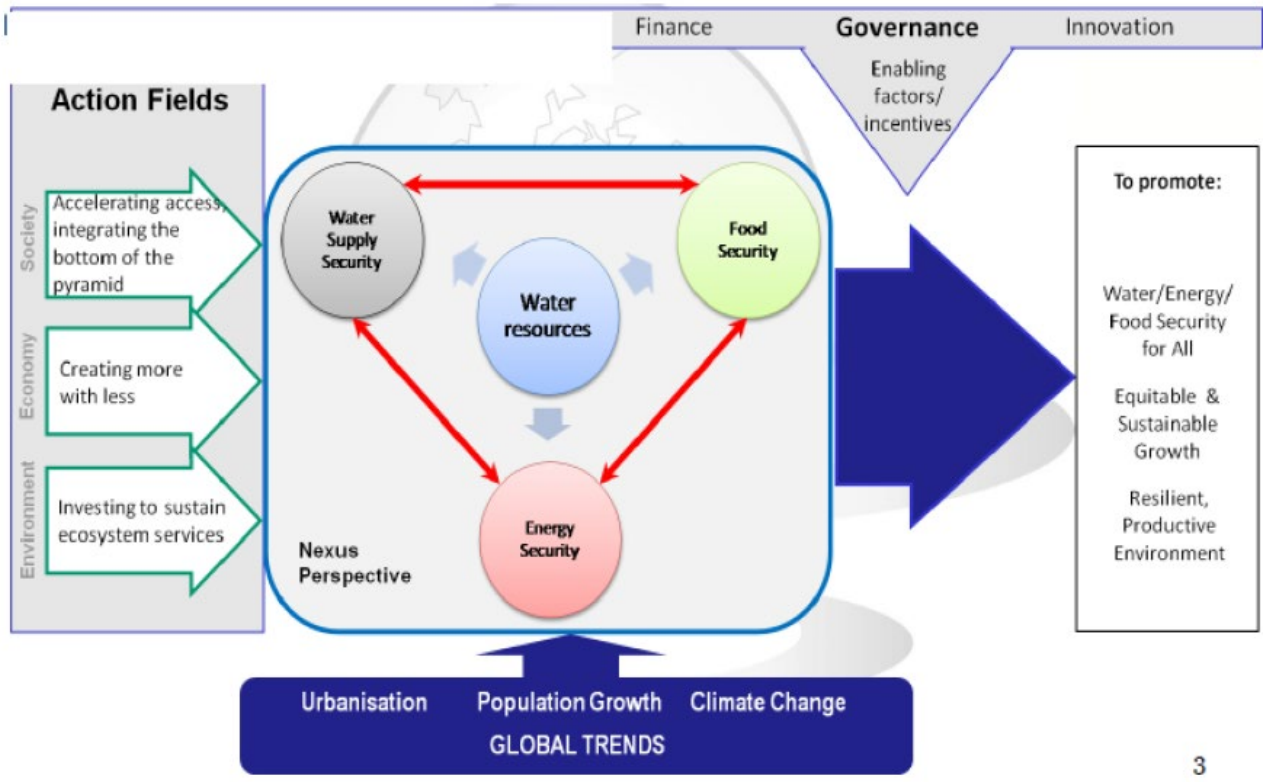


Figure 2.6: The water, energy and food and nutrition security nexus (Source: Hoff, 2011)

It is clear that water, energy and food nutrition security as basic needs have been crucial issues in human history dating back to the earliest days of civilization (Kim et al., 2015). Global human society must now attempt to solve a set of complex and interrelated problems that Diamond (2005) characterises as “fundamental threats to human civilisation”. Many of these issues are directly related to WEF production, distribution, and use especially in developing countries. However, until quite recently, these resources were not treated as a nexus, which are closely interdependent of each other, as it is not possible to address an issue of one system without considering its implications on the other systems.

In 1972, the Limits to Growth, the famous publication of the Club of Rome, developed a set of scenarios for possible futures and predicted that continued growth of the global economy, as resource extraction increases, would result in significant resource scarcities (Kim et al., 2015). The Limits to Growth introduced the concept that natural resource depletion will impact the ability of an economy to grow in the long run, and this was the first occasion attracting public interest globally on resource security as a significant threat to an economy. In 1987, Our Common Future, the report of the World Commission on Environment and Development (WCED), introduced a more comprehensive concept of the interdependency between natural resources and the economy (Kim et al., 2015). The concept of sustainable development was based on the interlinkages between economic, environmental, and social dimensions and has been incorporated into the global development agenda. However, even in the context of sustainable development, the integration of these three dimensions remains segmented. Resource security issues have been getting increased attention again in the context of the global crises in natural resources. The nexus between resources, particularly the water-energy-food nexus, came into existence as a new approach to address water, energy and food nutrition security issues in line with sustainable development.

The WEF nexus is central to sustainable development and has been highlighted as critical to achieving the SDGs and the South African national priorities. The SDG of zero poverty (SDG1), ending hunger and food insecurity (SDG 2), ensuring water security (SDG 6), access to modern energy (SDG 7), sustainable economic growth (SDG 8), industry, innovation and infrastructure (Goal 9) through innovations linked to WEF nexus resource utilisation, development, management of sustainable consumption and production (SDG12), and conservation, protection, and sustainable use of marine and terrestrial resources and ecosystems (SDGs 14 and 15) are all closely interlinked and success in achieving them will depend heavily on ensuring the sustainable use and management of water, energy, land (food), and other natural resources (Rasul, 2016). The nexus resources are not only interdependent, but they also reinforce and impose constraints on one another (Rasul, 2014; Weitz et al., 2014; GDI, 2015; Rasul and Sharma, 2016 and IUCN ROWA, 2019). The goals of each of them are interlinked in different ways. Achieving the goal of food security and ending hunger, for example, depends strongly on achieving water and energy security, which is needed to ensure water and energy are available for food production. Similarly, the ability to achieve the goal of water and energy security will largely depend on how food is produced, processed, transported, and consumed (Hussey and Pittock, 2012). Enhancing the efficiency of water, energy, and land use can ease trade-offs and resource conflicts. Despite the inherent interconnectedness of food, water, and energy, there is still much that needs to be done in order to understand the interdependencies in terms of resource use and policies, particularly at the household level. Understanding and managing the links among food, water, and energy is essential for formulating policies for more resilient and adaptable societies (Newell et al., 2011).

Nerini et al. (2017) reported that the WEF nexus could mitigate climate risks in southern Africa. This assertion is supported by Nhamo et al. (2019), who argue that southern Africa is highly vulnerable to drought because of its dependence on climate-sensitive sectors of agriculture, hydro-energy and fisheries. Mpandeli et al. (2018) reported in their study that climate change adaptation through the WEF nexus is imperative. Mabhaudhi et al. (2019) supported this assertion, arguing that the WEF nexus is a potential tool to transform rural livelihoods and well-being in Southern Africa.

According to Mabhaudhi et al. (2019), the WEF nexus provides better adaptation options, as it guides decision making processes by identifying priority areas needing intervention, enhancing synergies, and minimising trade-offs necessary for resilient rural communities. They developed a WEF nexus livelihoods adaptation and transformation framework which identified (i) the trade-offs and unintended negative consequences for poor rural households' livelihoods of current silo approaches, (ii) mechanisms for sustainably enhancing household water, energy and food security, whilst (iii) providing direction for achieving SDGs 2, 3, 6 and 7.

2.6 WEF nexus research in South Africa

A number of studies have been conducted to assess the application of the WEF nexus approach in South Africa. Mabhaudhi et al. (2018a) conducted a study in which they assessed the state of the WEF nexus in South Africa. In addition, they conducted a literature review on past, present and ongoing work on the WEF nexus focusing on current status, potential, challenges and opportunities for inter-sectoral WEF Nexus planning. Seeliger et al. (2018) conducted a study in which they applied the WEF nexus to farm profitability in the Middle Breede Catchment, South Africa. They demonstrated how the WEF nexus approach could provide insights into how integrated water management can be applied in a particular agricultural context. Mabhaudhi et al. (2019), in their study, argued that a better understanding of the policy and institutional dimensions at the household scale is important for the nexus approach to have a greater impact. According to the study of Nhamo et al. (2020), who developed an integrative analytical model for the WEF nexus and applied it to assess progress

towards the Sustainable Development Goals in South Africa, the country's management of the nexus resources is marginally sustainable.

To date, nexus framings and applications of the nexus approach have tended towards technical assessments to enhance productivity, optimise synergies and identify trade-offs across nexus sectors to inform natural resource governance (Howells et al., 2013). However, resource 'security is not solely driven by the availability of the resources but also by access to resources, the capacity to utilise resources, and dynamics of social power relations and the strength of institutions (Ericksen, 2008; Pritchard et al., 2013). Various studies have shown that ineffective policies, governance and institutional arrangements are some of the main factors that limit access to and sustainable use of water, energy and land resources at the household level (Denison et al., 2016). Simpson et al. (2020) conducted research in which they developed the WEF nexus index and its application to South Africa and the Southern African Development Community.

Gulati et al. (2013) reviewed the level of interconnectedness between the WEF systems in South Africa and discussed how energy and water costs influence food prices in the country and affect the country's level of food and nutrition security. Botai et al. (2021) conducted a review of the WEF nexus research in Africa and contented that there is a need for more coordinated and collaborative research to achieve impact and transition from WEF nexus thinking to WEF nexus practice.

2.7 WEF nexus innovations and practices

According to Al-Saidi and Elagib (2017), there are three drivers behind the emergence of the WEF thinking. These are (a) increasing resource interlinks due to growing scarcities, (b) recent resource supply crises, and (c) failures of sector-driven management strategies. The unprecedented surge in urbanization and population growth rates is generating multiple impacts, affecting WEF demands (Arthur et al., 2019). Moreover, the adverse effects are extending to climate, as well as to human and ecosystem health. Water, energy, food, and nutrition securities are inextricably linked, with usage within one sector influencing the use and availability in the adjacent sectors. Therefore, coordinated efforts are often deemed critical to minimize trade-offs, while maximizing synergies among WEF sub-systems (Arthur et al., 2019). WEF nexus is about the interrelationships and trade-offs among system components includes energy supply, electricity generation, water supply-demand, food production as well as mitigation of environmental impacts (Zhang and Vesselinov, 2017). Simpson and Jewitt (2019) explain it as "water for food and food for water, energy for water and water for energy, and food for energy and energy for food." The nexus, if handled systematically, is viewed as a fresh way of thinking about related issues (Harwood, 2018).

2.7.1 Water sub-system

Water plays an important role in almost every stage of energy development, including extraction, production and processing of fossil fuels, electricity generation, and treatment of wastes from energy-related activities (Hoff, 2011; Mo et al., 2014; Fulton and Cooley, 2015; Perrone et al., 2011; Bartos and Chester, 2014; Pereira-Cardenal et al., 2016). Water is needed for food production, mainly for irrigation and processing crops. Agricultural production is the largest consumer of water globally, accounting for about 90% of global freshwater consumption in the past century (Hoff, 2011; Khan and Hanjra, 2009; Shiklomanov, 2000). Conversely, energy is needed to pump, collect, treat, and distribute water; at the same time, energy is crucial in food production and processing for mechanization, land preparation, fertilizer production and application, irrigation, packaging, processing and storage of food (Hoff, 2011; Zhou et al., 2013), and about 30% of the global energy consumptions are from food production and supply (FAO, 2011).

2.7.2 Energy sub-system

A significant amount of water is required to generate energy. Also, direct resource consumption in the food sub-system and indirect operations in the energy sub-system cause environmental impacts (Li and Ma, 2020). Inversely, water can also be an alternating source of energy through hydro-power. Energy security is defined as: “the uninterrupted availability of energy sources at an affordable price”. A collapse of energy systems could disrupt food production, preservation, and supply (Olawuyi, 2020). Green-house-gas emission impacts WEF nexus management as well (Zhang and Vesselinov, 2017). Without water, we cannot produce food and energy; and without energy, we cannot process or distribute food and water (Olawuyi, 2020). The inextricable linkages between these critical domains require a suitably integrated and transformative approach to ensuring water and food and nutrition security and sustainable agriculture and energy production in South Africa. A nexus approach is an approach that considers the interactions, synergies and trade-offs of water, energy and food when undertaking the management of these resources can increase overall resource use efficiency, provide additional benefits and secure the human rights to water and food. De Grenade et al. (2016) pointed out that the WEF nexus fails to adequately acknowledge the environment as the set of natural processes underpinning the nexus, particularly interactions among water, energy, and food. The institutional framework governing the elements of the WEF Nexus is mostly fragmented.

2.7.3 Food sub-system

Irrigated agriculture is a key example of the WEF nexus due to the strong competition over water used for energy generation and water used for food production in water-scarce areas of the world (Avellan et al., 2018; Stamou et al., 2018: Liu et al, 2019). In South Africa, agriculture is the largest water user at 60% of total water use, followed by municipal use at 27% (including industrial and commercial users provided from municipal systems), rural domestic at 5%, with power generation, mining and bulk industrial use, livestock and conservation and afforestation jointly making up the remaining 8% (Mwendera and Atyosi, 2018).

2.8 Concept of smart innovations and practices

IGI Global, define smart innovation as the ability to create new opportunities through a continuous relationship with the main actors in a destination, fostering an innovate operational approach in an effective way in order to ameliorate local efficiency and innovation, thus gaining sustainable competitive advantage2. WEF smart innovations and practices are those that ensure not only water and energy conservation but also other benefits. For example, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) implemented water management innovations that benefited not only a number of smallholder farmers but also helped decision-makers develop programs for the improvement of water supply in agriculture3. In India, CCAFS piloted a Solar Pump Irrigators’ Cooperative (SPICE) model using an innovative business model, whereby farmer-members’ solar irrigation pumps are connected to each other in a micro-grid. Once the farmers are done with irrigation, they pool their surplus solar energy and sell it to a local power distribution company4. Hence, this innovation helps in controlling groundwater overexploitation, reducing the carbon footprint of agriculture, and increasing farmer incomes.

The global challenges are growing population, triple-burden of malnutrition5 and climate change disasters. Smartness of innovation and practices emanate from Nutrition-Sensitive Climate-Smart Agriculture. Climate-smart agriculture (CSA) is an integrated approach to

2 https://www.igi-global.com/dictionary/smart-innovation/39258
3 https://impakter.com/the-value-of-water-smart-agriculture/
4 Ibid
5 Triple burden of malnutrition refers to the coexistence of overnutrition, undernutrition and micronutrient deficiencies

managing landscapes – cropland, livestock, forests and fisheries--that address the interlinked challenges of food security and climate change. CSA6 aims to simultaneously achieve three outcomes: 1) Increased productivity, 2) Enhanced resilience, and 3) Reduced emissions. Nutrition-sensitive Agriculture (NSA7) incorporates specific nutrition objectives ensuring that WEF nexus delivers positive nutrition outcomes through making food more available and accessible and making food more diverse and production more sustainable. Furthermore, smart innovations should also be gender-sensitive. Therefore, water security (i.e. the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks) is imperative.

These are examples of smart innovations and practices which have multiple benefits to the users and beyond. It is in the context of these definitions and examples that the study assessed smart innovations and practices in the study area.

2.9 WEF nexus at the household and community levels

The assessment of implementing the WEF nexus innovations and practices at the household level can be considered through its link to the livelihoods of the people. According to Biggs et al. (2015), the framework consists of internal factors (livelihoods, water, energy and food) which are influenced by external factors (hazards, economic growth and pressure, and institutions and policies), as illustrated in Figure 2.7.

Nhamo et al. (2020) researched the water-energy-food nexus as an adaptation strategy for achieving sustainable livelihoods at a local level in South Africa. In their study, Nhamo et al. (2020), applied an integrated WEF nexus analytical model to holistically assess the availability, distribution, use and management of WEF resources at a local level in Sakhisizwe Local Municipality, South Africa. They concluded that, unlike current linear approaches, integrated and transformative approaches like the WEF nexus provide a multidisciplinary platform for stakeholder engagement to sustainably enhance cross-sectoral coordination of resource management and harmonisation of policies and strategies.

6 Climate-smart agriculture
7 Nutrition Sensitive Agriculture

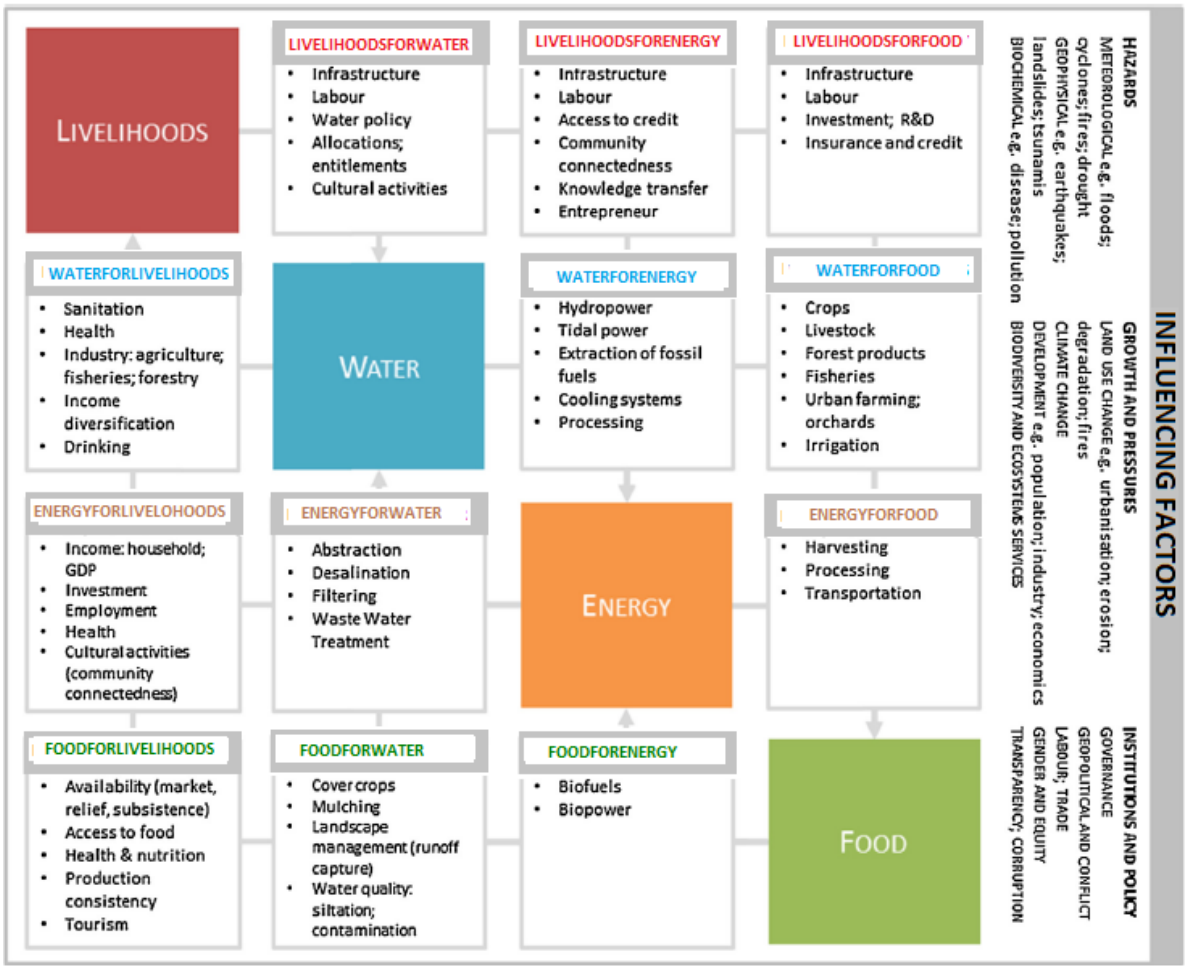


Figure 2.7: Water-water-energy-food nexus linked to livelihoods at the household level (Source: Biggs et al., 2015)

Foden et al. (2018) conducted a study on the water-energy-food nexus at home and explored new opportunities for policy interventions in household sustainability. In their study, they focussed specifically on domestic kitchens as a site where practices of cooking, eating, cleaning and disposing of waste come together. They argued that these practices have long been targets for policy intervention. They were able to demonstrate that the nexus of WEF is as apparent at the household scale as it is anywhere else, and they introduced the concept of the “Nexus at Home” as a starting point for exploring the dynamics of WEF resource use and household sustainability. Their study focused on fats, oils, and grease (FOG) going down the kitchen plughole, contributing to widespread sewer blockages. Foden et al. (2018) document the sequence of interrelated food provisioning activities through which WEF is used in domestic kitchens and contributes to FOG blockages in sewers. They reflected upon the multiple ways these practices are shaped by the rhythms of daily life, dynamics within the home, wider cultural conventions.

Hussein et al. (2017) developed an integrated model, capturing WEF interactions at the end-use level at a household scale in Iraq. The model estimates WEF demand and the generated organic waste and wastewater quantities. The model is also used to investigate the impact of change in user behaviour, diet, income, family size and climate on the use and management of WEF resources at the household level.

Terrapin-Pfaff et al. (2018) brought the household dimension of the WEF nexus approach through their study in which they conducted a systematic analysis of the linkages between

small-scale energy projects in developing countries and the food and water aspects of development. Their study provides initial insights into how to identified interconnections and the potential benefits of integrating the nexus pillars into local level projects, and it also identified the complex links which exist between sustainable energy projects and the food and water sectors and highlighted that these needs are currently not systematically integrated into project design or project evaluation.

2.10 Policy dimension of the WEF nexus

Gulati et al. (2013) report that policies related to different sectors of the economy could intensify or attenuate the interdependence: or worse, ignore the impact of one on the other and adversely impact the overall nexus. Bizikova (2019) conducted a comparative review of case studies to explore integrating the identified nexus linkages into policy design and implementation. He focussed on local and regional challenges in the nexus context, using diverse research methods to assess WEF linkages and the activities integrating identified WEF linkages into the public policy design. He argued that designing successful, policy-relevant WEF assessments depends on focusing on synergies and trade-offs within the nexus; adopting solutions-centred approaches to challenges identified at the earlier stages of assessments; and effectively managing science and policy linkages through institutional partnerships and collaborations between researchers undertaking WEF assessments and key policy and decision-making agencies. In their book, Koulouri and Mouraviev (2019) argue that effective engagement of multiple stakeholders can address difficulties arising from introducing an integrated approach to WEF policy design and implementation, increasing the potential benefits.

Shannak et al. (2018) pointed out that WEF resources are complex aggregates formed and influenced by the collection of elements, and managing them relies on several factors such as technology choices, fuel choices, resource availability and market factors, which can all be affected by national resource policies. Scott and Pasqualetti (2010) reported that multi-tiered institutional arrangements – specifically laws, policies, and organizations that operate across jurisdictional levels for the management of resources – offer a wider set of alternatives for decision-making in the management of water and energy resources.

Scott et al. (2011) conducted a study on the water-energy nexus policy dimensions in the United States of America. They found that contemporary water policy does consider the energy implications of water use, although often in basic terms of increased financial costs for the energy required to pump, treat, and reclaim water. Sovacool and Sovacool (2009) and Carter (2010) reported that it is important that national energy policy initiatives actively consider water resource implications.

Kim et al. (2015) reported that numerous recent studies had emphasized the significant roles of the energy-water nexus, but institutional and policy directions of the nexus have not been dealt with significantly. Their study focussed on identifying policy dimensions that support the nexus interactions between water and energy systems and various nexus-based solutions that can address sectoral issues in both systems. Shah (2016) conducted a study in which he used the nexus model to integrate water, energy and food for the development of policy framework and its realization. He argued that the nexus model had been used as a suggestive framework for the policy-making for the realization of UN-SDGs.

According to Hamdy et al. (2014), effective implementation of the nexus approach allows decision-makers to develop appropriate policies, strategies and investments, to explore and exploit synergies, and to identify and mitigate trade-offs among the development goals related to water, energy and food and nutrition security.

Gulati et al. (2013) argue that there is an imbalance in the way the nexus plays out in the policy landscape in South Africa, in that the energy and water policies are developed in

isolation with no links to each other. Thus, for example, while the aspects of cost, carbon, and energy security have been given significant attention, water needs have not been part of this process. Similarly, energy pricing has not formed part of the water pricing strategy for South Africa to date (Gulati et al. (2013).

2.11 Governance and institutional dimensions of the WEF nexus

Governance is defined as a government's ability to make and enforce rules and deliver services *(*Fukuyama, 2013*).* On the other hand, Rogers and Hall (2003) refer to water governance as the range of political, social, economic and administrative systems that are in place to develop and manage water resources and the delivery of water services at different levels of society. According to the Water Governance Facility[8]., governing water includes the formulation, establishment and implementation of water policies, legislation and institutions, and clarification of the roles and responsibilities of government, civil society and the private sector in relation to water resources and services, and that the characteristics or the attributes of governance have also evolved from a state-centric and hierarchical problem-solving approach to 'good' governance, promoting openness, efficiency, the rule of law, justice, transparency, accountability, broad participation, decentralization and deliberation (Graham et al., 2003). Thus, Jiménez et al. (2020) argue that water governance is a combination of functions, performed with certain attributes, to achieve one or more desired outcomes, all shaped by the values and aspirations of individuals and organisations. Chiluwe and Nkhata (2013), presented a review of the enabling environment for effective water governance in Malawi by specifically determining the extent to which water legislation and policies of Malawi reflect international water governance principles of participation, accountability, and transparency.

According to Scott (2017), governance for the WEF nexus can be understood as the formal and informal processes and institutions for integrated policy- and decision-making across the WEF sectors. He further argues that this has similarities with environmental governance, which may be described as the regulatory processes and organisations used by different actors to influence environmental actions and outcomes, and the governance of food security, described by Food and Agriculture Organisation (FAO) as the "formal and informal rules and processes through which interests are articulated and decisions relevant to food and nutrition security in a country are made, implemented and enforced". Governance of the WEF nexus includes a wide range of private and public systems that manage the supply and demand of water, energy and food (Pahl-Wostl, 2019). Simpson et al. (2020) argue that the WEF available literature shows that the nexus framework holds promise for guiding policy development and governance structures in a world facing climate change, population growth, and inequality in terms of access to resources. Al-Saidi and Elagib (2017) suggest that a governance focus is one of the missing ingredients in the nexus debate. The concept of governance is defined differently by different academics (see Kooiman, 1993; Rhodes, 1997; Pierre and Peter, 2000; Osborne, 2010; Klijn and Koppenjan, 2012; Fukuyama, 2013). In this study, the stance of Fukuyama (2013) that governance's core is the execution of policy goals is adopted. Fukuyama (2013) further argues that, in a more detailed way, governance can be defined as an institution's ability to make and enforce rules and deliver services; hence the quality of governance is defined as the ability of the institution to get things done. In this study, we assess the execution of policy goals in relation to the WEF nexus at the household level.

Cairney (2016) argues that the governance and institutional landscapes and the processes, norms, rules and interests that dictate how resources are allocated critically influence how technical information on trade-offs between sectoral objectives is translated into action. A generally agreed principle is that sustainable development requires distinct environmental, social and economic policies combined with more integrated decision-making across all sectors of society (Nilsson et al., 2016). However, these conditions are rarely observed and

8

present a paramount challenge, which is addressed in the academic literature under various concepts of integrative environmental governance (Jordan and Lenschow, 2010; Adelle and Russel 2013; Visseren-Hamakers, 2015). The challenge of achieving such integrated decision-making and policy coherence is particularly acute in the context of the WEF nexus, which considers three sectors and policy areas with different institutional frameworks operating at different scales (Scott et al., 2011).

In their case studies, Mouraviev and Koulouri (2019a) concluded that the successful integration of the WEF nexus conceptualisation for the governance of these sectors is contingent on the effective management of the relational equity of all stakeholders/actors. They adopted the view on collective governance as an arrangement that brings together various actors and public agencies in collective forums, to engage in problem-solving-focused and consensus-oriented decision-making and that the collaborative approach is one of the most impactful means of nexus governance, enabled and facilitated by effective relational equity management. In their other study, Mouraviev and Koulouri (2019b) concluded that among the critical governance areas that require attention are: the integration of climate change in all nexus considerations at all stages, from policy design to implementation; recommendation to depart from unidimensional approach to energy security, water security or food and nutrition security and replace it with multidimensional; a suggestion to hold an ongoing transparent polylogue between all nexus network participants; securing network participants' commitment to the outcomes for the WEF nexus, rather than for a certain sector. Srigiri and Dombrowsky (2021) argue that while WEF scholarship substantiates the biophysical interlinkages and calls for increased and effective coordination across sectors and levels, knowledge about the conditions for effective coordination is lacking. They further argue that effective coordination in complex social-ecological systems is unlikely to be achieved by a single governance model but rather by synergistic combinations of such modes. Particular coordination arrangements that emerge in a given context depend on the distribution of authority, information and resources within and across interlinked decision-making centres.

Naidoo (2021), in one of his presentations, emphasized that the WEF resources crisis is rooted more in poor governance than in physical availability; hence, good governance holds the key to achieving sustainable water, energy, and food and nutrition security in Africa.

Weitz et al. (2017) reported from their work on closing the governance gaps in the water-energy-food nexus that connecting the nexus to decision-making processes requires: i) rethinking the boundaries of nexus analysis vis-à-vis other sectors and levels; ii) elaboration of shared principles that can guide decision-making towards policy coherence − or an appropriate form of fragmentation − in different contexts; iii) viewing policy coherence as a continuous process of changing values and perception rather than as an outcome.

2.12 Synthesis and analysis of the existing body of literature

2.12.1 Summary of key findings on the existing body of literature

The review focused on the body of literature that covers areas such as global perspectives of WEF nexus, the need for WEF nexus solutions, WEF nexus interlinkages and frameworks, the WEF nexus research in South Africa, WEF nexus innovations and practices, policy and governance dimensions of WEF nexus and the application of WEF nexus solutions at the household and community levels. literature also provides a wide range of approaches and methods used to study WEF nexus approaches.

The literature shows that there is growing pressure on the WEF resources and that the WEF nexus approach offers the best ways of managing and utilising the resources sustainably. Sustainable management of the WEF resources requires effective policies and governance systems that create enabling environment for implementing WEF nexus solutions. The literature shows that various WEF nexus frameworks have been developed to understand the

complexity and linkages of the nexus resources and provide tools for operationalised the nexus approach. The literature also shows a great need for appropriate WEF nexus innovations and practices that help translate the WEF nexus approach from theory into practice. There is a great need to operationalise the WEF nexus solutions at the household and community levels.

2.12.2 Assessment of the gaps in the existing body of literature

The review findings showed that while so much research has been conducted on the WEF nexus approach, there are some areas that still need more research. It is clear from the existing body of literature that there is a lot of research on WEF nexus in general. However, more research is needed to address WEF nexus related innovations and practices and policy and governance dimensions of WEF nexus. In their report, where they reviewed the water-energy-food nexus research in Africa, Botai et al. (2021) contended that, while there is a lot of research which has been conducted on WEF nexus, there is need for more coordinated and collaborative research to achieve impact and transition from WEF nexus thinking to WEF nexus practice. This is why the current research focused on WEF nexus innovations and practices to move WEF nexus from theory to practice. This assertion is supported by Markantonis et al. (2019), who pointed out that the WEF nexus concept still needs to be translated from theory to practice. There is a great need to operationalise the WEF nexus solutions at the household and community levels. This household and community transformation requires understanding the existing and potential WEF nexus innovations and practices applied at the household and community levels and how existing policies and governance systems affect the use and management of WEF resources at these levels.

2.12.3 The link of current research to the existing body of knowledge

There are clear links of the current study to the existing body of knowledge as contained in the reviewed literature. Much of the reviewed literature shows that transitioning from theory to practice in the WEF nexus requires multi-sectoral stakeholder capacity building to manage the interlinkages between resources, effective policies and governance systems, and technological innovations and practices. The existing literature also shows that improving the understanding of the nexus approach through innovations and practices is key to the nexus implementation and informs planning and decision making for policymakers and other stakeholders. Furthermore, it is contended that the lack of innovations may hinder the implementation of WEF nexus agendas that allow, for example, the production of more food with less water and energy resources to help attain SDGs on poverty eradication (Goal 1), zero hunger (Goal 2), availing water to all (Goal 6) and provision of clean energy (Goal 7) (Hoolohan et al., 2018; Mabhaudhi et al., 2018b).

The literature review findings showed that there is a need to understand the existing and potential WEF nexus innovations and practices applied at the household and community levels and how existing policies and governance systems affect the use and management of WEF resources at these levels. The current study is focusing on these areas and thus shall contribute immensely to the literature body of knowledge.

2.13 Conclusions and recommendations

A review was conducted on the body of literature that covers areas such as global perspectives of WEF nexus, the need for WEF nexus solutions, WEF nexus interlinkages and frameworks, the WEF nexus research in South Africa, WEF nexus innovations and practices, policy and governance and institutional dimensions of WEF nexus and the application of WEF nexus solutions at the household and community levels. The review findings show that there are various methods and approaches for conducting research on the WEF nexus approach. The current research benefited from the wide range of approaches and methods various researchers have used to study the WEF nexus approach. These approaches provided the basis for developing the methodology for the current study. The literature review findings also highlighted the need to understand the existing and potential WEF nexus innovations and

practices applied at the household and community levels and how existing policies and governance systems affect the use and management of WEF resources at these levels. The current research focused on WEF nexus innovations and practices applied at the household and community levels, and on how existing policies and governance systems affect the use and management of WEF resources at these levels. There is need to expand the scope of the review in future research.

3 CHAPTER 3: RESEARCH METHODOLOGY

3.1 Purpose and objectives

The main purpose of the research methodology was to give the research study legitimacy and to ensure that the research provides scientifically sound findings. It also provided a detailed plan that helped to keep the research team on track, making the process smooth, effective and manageable. The methodology also basis upon which readers of the report can understand the approach and methods used to reach the research conclusions.

3.2 Research methods and approaches

The research methodology comprised of four distinct but interrelated Work Packages, which covered the identification of WEF nexus innovations and practices and policy, governance and institutional frameworks.

Work Package 1: Desktop study and selection of study communities and sectors in Vhembe District

The research will involve a desktop study in which an in-depth review of literature on research themes related to WEF nexus innovations and practices, policy, governance and institutional dimensions will be carried out. The desktop study will also involve a comprehensive review of scholarly articles and national and provincial reports and documents to identify relevant innovations and practices, policy, governance, and institutional settings for the WEF nexus approach. The desktop study will also be used to identify the communities' socio-economic context and general conditions in the study areas. This will include information on the current state of energy, food, water and environmental security, and the availability of natural resources, and the relations that exist within the areas. A literature review (previous section) shall be used to develop a comprehensive WEF nexus framework (i.e. data collection tool) that will be used to identify WEF innovations and practices as well as institutional and governance frameworks.

3.2.1 Selection of study communities and sectors in Vhembe District

Together with the relevant authorities, knowledge of academics from the University of Venda on research catchments in Vhembe District, and desktop and field survey, the project will identify the communities to be involved in this study. In corresponding with key actors (competent authorities, utilities, etc.) the key sectors to be analysed in the assessment (water supply, power production, agriculture, socio-economic factors and others). The actors will be local authorities, members of the community, municipal officials, Eskom officials and government officials particularly from the Department of Water and Sanitation and the Department of Agriculture, Land Reform and Rural Development (DALRRD).

Target communities for involvement in the study will be rural communities in Vhembe District living in rural settlements with low income, fast-growing peri-urban centres and small-scale farmers along the Nzhelele and Luvuvhu River Catchment areas. These target groups are of interest due to critical water, food and energy scarcity associated with lack of infrastructure, inadequate water resources and inadequate supply and management of the resources. Poverty, inequality and lack of knowledge on WEF nexus and the synergies associated with the latter are also prevalent among them.

Work Package 2: Identifying, mapping and assessing WEF nexus innovations and practices

This will involve identifying and quantifying the WEF nexus smart technologies, innovations and practices in the study area. In this case, the use of the concept "technologies" is inclusive of innovations and practice. This will involve fieldwork, surveys and observations to collect water, energy and food resource data.

3.2.2 Identification of promising technologies

In the project methodology, focus group discussions (with project stakeholders) and expert interviews (with WEF experts and development practitioners) with relevant stakeholders will be used to select candidate WEF technologies before they can be recommended to the testing stage. Co-creation of solutions will be an underpinning principle. The main output from this main activity will be a refined list of promising WEF nexus technologies relevant for the Nzhelele and Luvuvhu River Catchment Areas from the co-created typology of promising technologies. There will be a Report on the results of the innovation platforms (i.e. convened for co-development of catchment area solutions) as a deliverable. Noteworthy, the study shall be limited on identifying and recommending these promising technologies and not implementation thereof at this stage.

Work package 3: Policy, governance and institutional structures analysis

The study will use a resource-policy approach to examine the fundamental human-environment challenges of water, energy and food coupling at the local level. The other area the study will examine is how local physical and social dynamics of water, energy and food development influence broader uses and demands for resources. It will also examine how the implementation of water-energy-food nexus approach feeds back to national change processes, economic growth (particularly in expanding urbanisation), rural community development, climate change and variability (through resource use that influences emissions), and interlinked markets (of water, energy and food). These are fundamental policy challenges that stem from the inextricable linking of the three most precious resources. The approach in this study is based on the dynamic relationship among food, water and energy sectors with the policy links as shown in Figure 3.1.

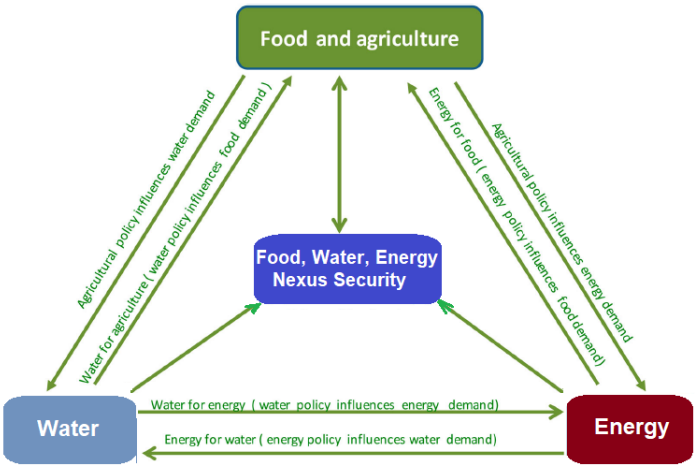


Figure 3.1: Dynamic relationship among the food, water, and energy sectors (Source: Rasul, 2016)

3.2.3 Assessment of the existing policy, governance and institutions systems

This section covers the assessment of how existing policy, governance and institutional systems affect the implementation of WEF nexus practices. The policy framework of Rasul

(2016) is presented in Figure 3.2 while the governance frame of Jiménez et al. (2020) is presented in Figure 3.3.

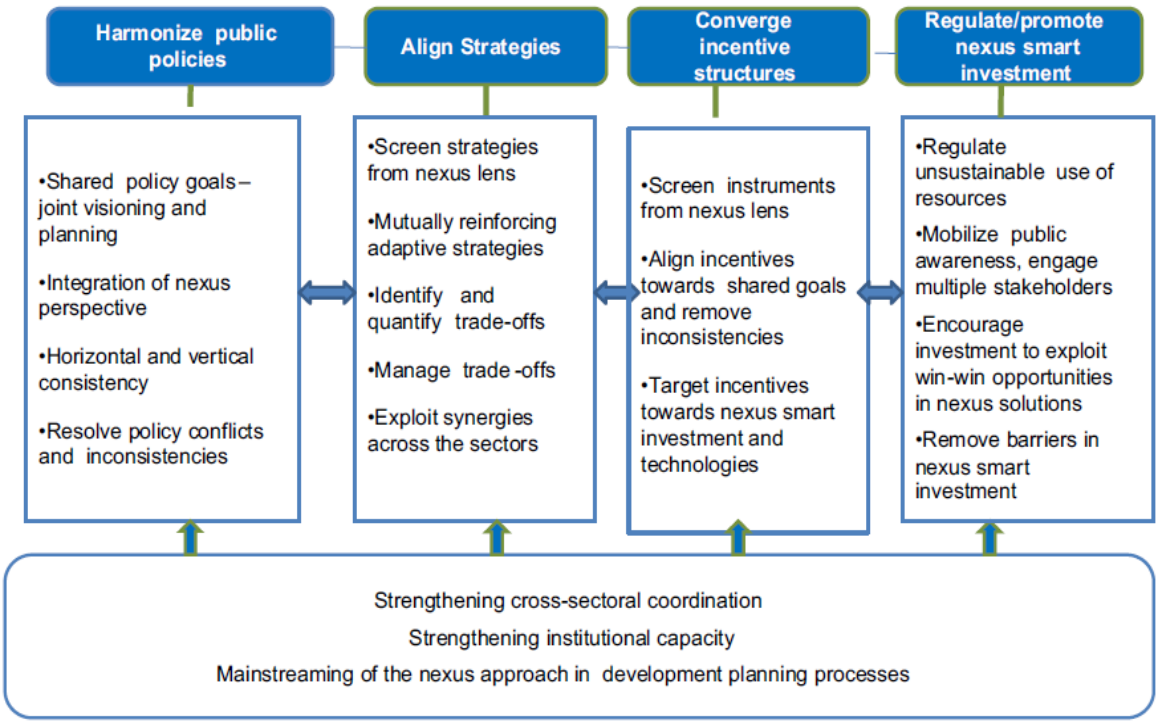


Figure 3.2: Policy framework for managing the WEF nexus
(Source: Rasul, 2016)

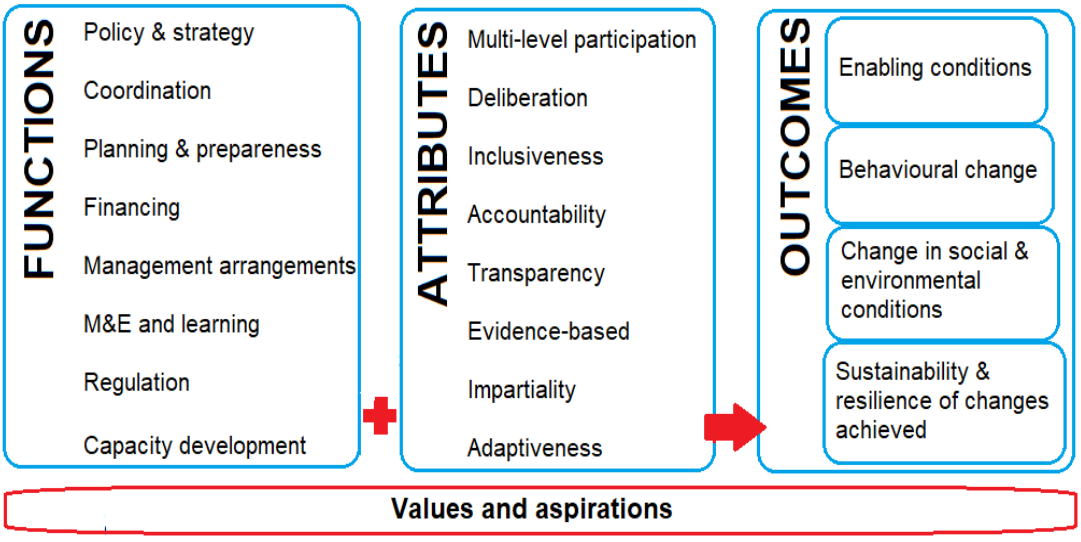


Figure 3.3: WEF nexus governance framework
(Adapted from: Jiménez et al., 2020)

The key elements of the WEF nexus policy framework in Figure 3.2 above are: strengthening cross-sectoral coordination; harmonizing public policies; aligning cross-sectoral strategies and incentive structures; strengthening regulation; and facilitating investment in nexus smart technologies (energy and water-saving technologies).

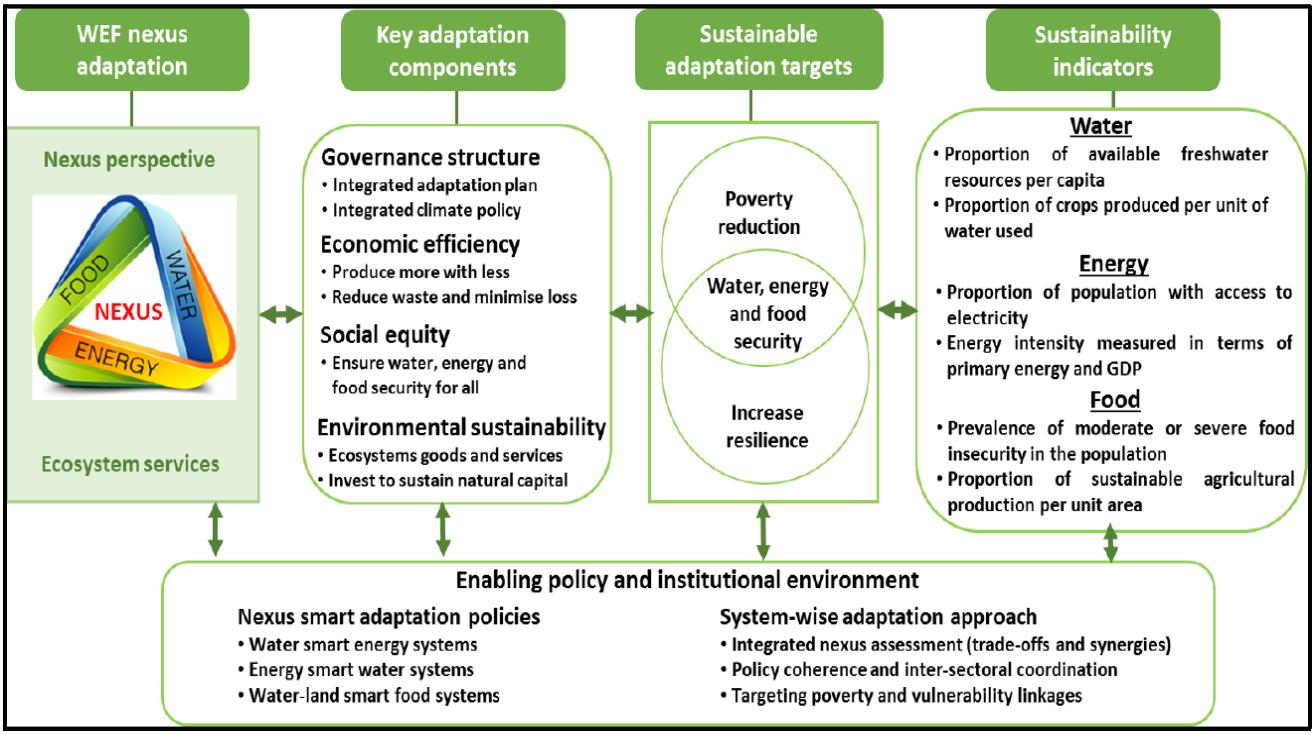


Figure 3.4: WEF nexus livelihoods adaptation and transformation framework (Source: Mabhaudhi et al., 2019)

According to Mabhaudhi et al. (2019), the transformation of rural livelihoods and the sustainability of adaptation strategies is underpinned by the understanding of the role of the WEF nexus in framing effective policies and institutions. Figure 3.4 represents a WEF nexus adaptation framework for assessing, monitoring and improving resource utilisation and management to ensure sustainable livelihoods transformation.

The first component of the framework in Figure 3.4 depicts the WEF nexus as a tool to enhance climate change adaptation and resilience for sustainable livelihoods and the environment, which illustrates the intricacies in the interlinkages among the WEF nexus sectors. These envisaged outcomes are achieved through the key adaptation strategies of governance (policies and plans), social equity (accelerating access for all), environmental sustainability (investing to sustain ecosystem services), and economic efficiency (increasing resource efficiency), as shown in the second component (Rasul and Sharma, 2016). These four key adaptation components form the basis to meet sustainable targets of reducing poverty and building resilience, which result in the security of resources, and sustainable development. The targets define sustainability indicators (last component of the framework) that assess and monitor resource planning and management, and to ensure equitable resource distribution and inclusive development. WEF nexus sustainability indicators are measurable parameters that indicate the performance of resource development, and monitor how the development is impacting on livelihoods or vice-versa (Nhamo et al., 2019). The essence of the indicators is to connect statements of intent (objectives) and measurable aspects of natural and human systems. The four components of Figure 9 are supported and underpinned by an enabling environment that oversees the WEF nexus implementation (Rasul and Sharma, 2016).

The policy frame in Figure 3.2 was used to assess the policy dimensions of WEF nexus. The study used and adapted the frameworks in Figures 3.4 and 3.4 for the analysis of the governance and institutional dimensions in order to develop an understanding of strategies, policies, institutions, rules and regulations, in addition to mandates, responsibilities and administration concerning the management of WEF resources in the study areas. The study

examined how policies, governance and institutions provide enabling conditions for influencing the effective application of the WEF nexus approach at the household level.

Work package 4: Developing or adapting a framework for improving policy, governance and institutional structures

This work package is designed to assess gaps and identify opportunities improving policy, governance and institutional dimensions. This will involve examining gaps in WEF Policy coherence and integration and identifying opportunities for improving policy, governance, and institutional structures to support effective implementation of the WEF nexus approach at the household level. At the end, the study provided recommendations to be integrated into the policy/decision-making processes and appropriate governance and institutional structure changes based on the study's outcomes. Rasul Framework and other frameworks was explored for further development or adaptation for improving policy, governance and institutional structures in order to support effective implementation of WEF nexus innovations and practices at household level in the study area.

3.3 Study location

The study was conducted in VDM, one of the five districts of the Limpopo Province in South Africa. The VDM is the northernmost district in South Africa and shares its northern border with Beitbridge district in Matabeleland South, Zimbabwe and on the east with Gaza Province in Mozambique. Vhembe District Municipality is a Category C Municipality, established in 2000 in terms of Local Government Municipal Structures Act No. 117 of 1998. The district covers 27 969 148 km^2 of land with a total population of 1 393 949 according to Stats SA, 2016 Community Survey. The district is divided into four local municipalities: Makhado, Thulamela, Musina, and Collins Chabane Local Municipalities, which are category B municipalities. The study was conducted in communities living in rural settlements with low-income, fast-growing peri-urban centres and small-scale farmers along the Nzhelele and Luvuvhu River Catchment areas. These target groups are of interest due to critical water, food and energy scarcity associated with a lack of infrastructure, inadequate water resources and inadequate supply and management of the resources. Data was collected in Nzhelele river catchment areas (Siloam, Khalavha, and Phadzima villages) and Luvuvhu river catchment areas (Sambandou, Tshakhuma and Maluvuwe villages) (Fig. 3.5).

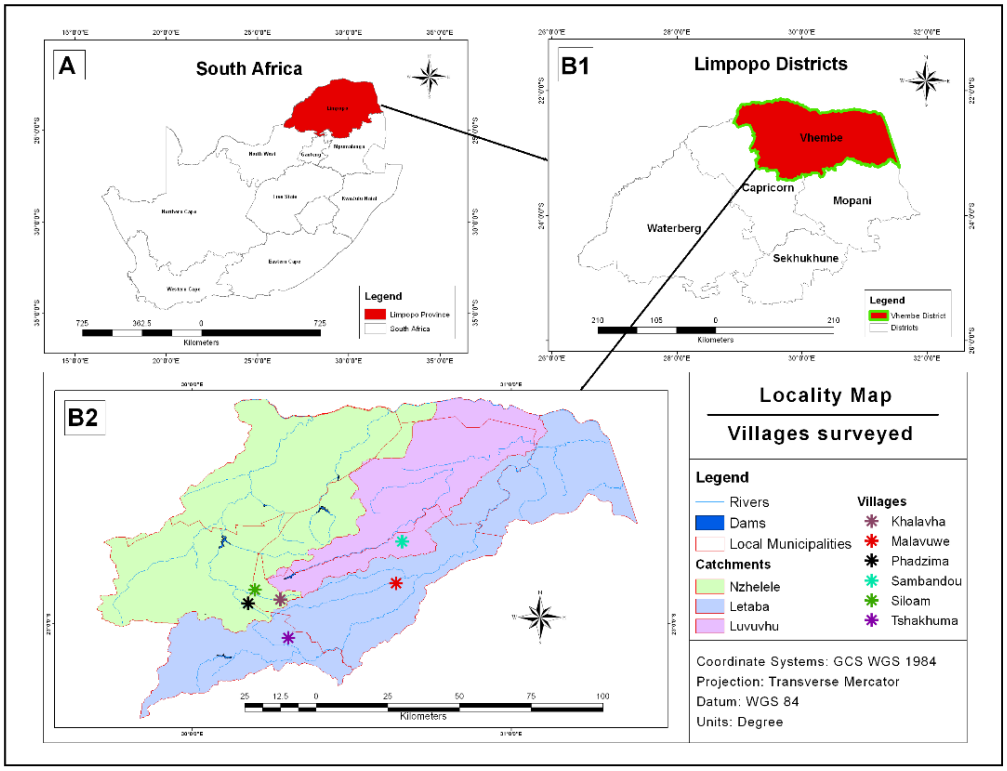


Figure 3.5: Location of the Vhembe District Municipality in Limpopo Province (Source: Research Team)

3.4 Target population

Target communities involved in the study were rural communities in VDM living in rural settlements with low-income, fast-growing peri-urban centres and small-scale farmers along the Nzhelele and Luvuvhu River Catchment areas. These target groups are of interest due to critical water, food and energy scarcity associated with lack of infrastructure, inadequate water resources and inadequate supply and management of the resources. Poverty, inequality and lack of knowledge of the WEF nexus and the synergies associated with the latter are also prevalent among them. Communities that were selected for the study were Siloam, Khalavha, and Phadzima that are part of the Nzhelele river catchment, as well as Sambandou, Tshakhuma and Maluvuwe that are part of the Luvuvhu river catchment (Fig 3.6).

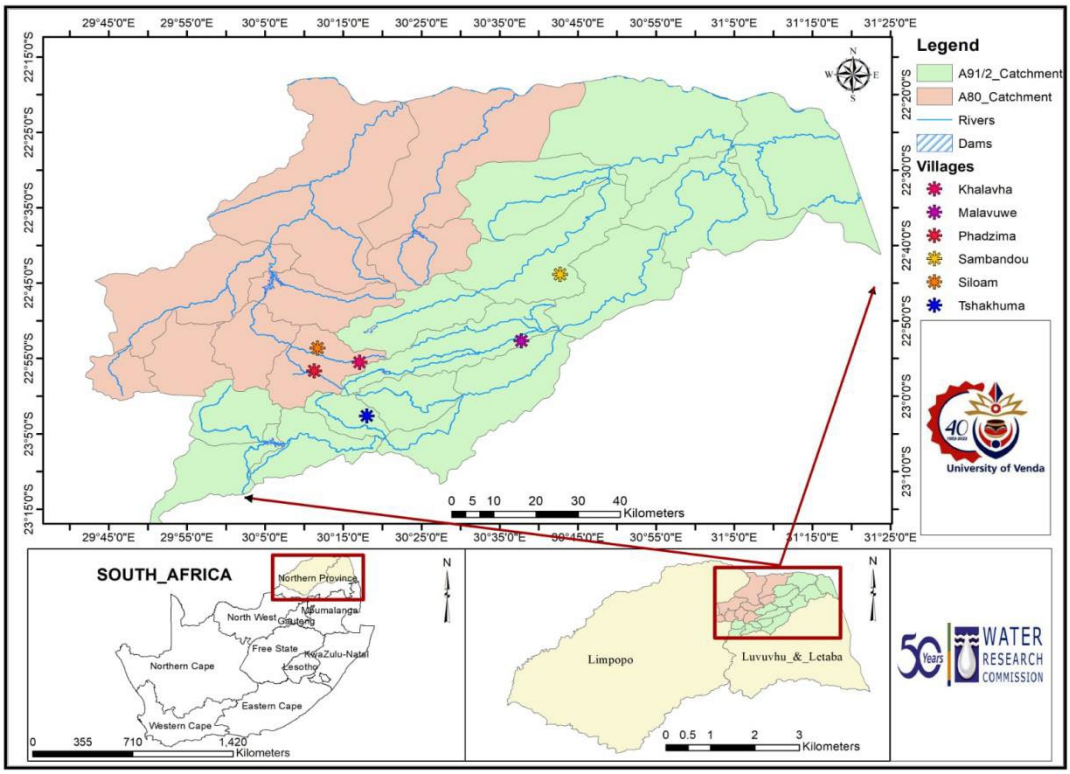


Figure 3.6: A map showing selected communities that were surveyed
(Source: Research Team)

3.5 Research design

The research design used a combination of both qualitative and quantitative research methods. The qualitative and quantitative methods include the collection and analysis of data over a period of time (Creswell, 2014). Understanding a research problem more thoroughly and responding to research questions must be based on a credible research approach (Cohen et al., 2018). Thus, these methods were used in this study because they employ strategies in inquiry such as experiments, surveys, and collect data on predetermined instruments that yield statistical data (Creswell, 2014).

The explorative, descriptive, narrative, and analytical aspects of the qualitative mode of research complement one another, which mitigates to a certain extent the bias and prejudices of both the researcher and the research participants (Johnson and Onwuegbuzie, 2007; Halcomb and Hickman, 2015; McCusker and Gunaydin, 2015; McKim, 2017). Quantitative research sets out to gather data using measurement to determine trends, relationships, and verify the measurements made (Watson, 2015). The techniques used in quantitative research include the selection of research participants from the study population in an unbiased manner, the standardized questionnaire or intervention they receive, and statistical methods (Muhammad et al., 2023). The main focus of this quantitative method was to compare WEF nexus in the study area to establish patterns and relationships.

3.6 Sampling procedure and sampling size

3.6.1 Sampling procedure

Resource insecurities and climate change are some of the existential risks faced by humanity. Since risk is one of the reasons that account for innovation in an organisation and social system (Nair et al., 2016), fast and frugal heuristic logic (Hafenbrädl et al., 2016) in sampling and sample size determination was adopted. Where evidence suggests risk disposition consensus, fast and frugal heuristics logic is normally adopted by selecting few representative cases as it does not compromise accuracy in the analysis of the obtained data (Volenzo and

Odiyo, 2020; Hafenbrädl et al., 2016). For this diagnostic study, a cross-sectional survey design was used at the household level to collect information from households in two river catchment zones through a multi-stage sampling technique. In the first stage, a sampling frame of households was obtained from each village administration.

Due to security advisories, semi-structured questionnaires were only administered to volunteering households among the randomly included households at a central location. The team adhered to a schedule agreed upon by the local administration and selected household representatives. Only those households who were available as scheduled (128 out of targeted 200) were interviewed. The information from household surveys was triangulated through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs). The semi-structured questionnaire was developed based on a mixed research approach, i.e. the gathering of both quantitative and qualitative data.

3.6.2 Sample size

The study employed Fisher's formula as proposed by Singh and Masuku (2014) in determination of sample size as given by equation (1). Only those households who were available as scheduled (128 out of a possible 200 households from the sampling frame initially selected through random sampling) were interviewed). WEF resource insecurities and climate change are some of the risks experienced by households in Vhembe District Municipality. The pilot study by the research team revealed that only about 40% of the households were involved in Agriculture. Further the households implemented similar WEF innovations and practices. Hence, we adopted fast and frugal heustic logic (Hafenbrädl et al., 2016). In risk studies adoption of fast and frugal heuristics logic, allows for sampling and generalization from few representative as it does not compromise accuracy in the analysis of the obtained data (Volenzo and Odiyo, 2020; Hafenbrädl et al., 2016). The sample size was calculated using Equation 1.

$$n = \frac{Z^2 p(1-p)}{d^2} \quad (1)$$

n = desired sample size
Z = Standard normal deviate at 95% level of confidence = 1.96
P= proportion of target population estimated to have the characteristic under investigation (40% or 0.4) to maximize sample size (precision)
q= proportion of target population without the characteristic (1-p = 60% or 0.6)
d= level of precision corresponding to statistical significance level of 0.05 or 5%

.
Substituting for the values

n = Z^2 (p q)/d^2) = 1.962(.5* .5)/(.05)2 = 3.8416(.25)/.0025 = 188.16 hence 189 households (Eq. 2).

$$n = \frac{1.96^2 * 0.4(1-0.4)}{(0.05)^2} = 189 \quad (2)$$

Taking cognisance of non-response, 200 households were targeted, but only 128 households were available due to forementioned security challenges. In context of diagnostic risk assessment, a sample size of 128 households was considered large enough to allow for generalization and exploration of risk from innovation lenses adequate enough, more so given that the social economic structure and farming systems (mostly home gardens) are more homogeneous. Further, information from household surveys was triangulated through KIIs and FGDs.

3.7 Pilot study, questionnaire survey, focus group discussions and key informant interviews

3.7.1 Pilot study

The questionnaires were pre-tested on Ten (10) respondents from the five (5) Villages bordering the study area. This was important in order to confirm that the questions were clear, and translatable. This was to ensure that no mistakes were made during the questionnaire administration and to avoid ambiguity in the questions. The pre-testing revealed that there was a need to rephrase some of the questions, and a few mistakes and repetitions of questions were recognised. Following Neuman (2014), the participants were interviewed face-to-face. The average duration of an interview during the pilot survey was 2 hours to 2H30 minutes. Overall, a total of 40 questionnaires were administered: Siloam (5); Khalavha (18); Phadzima (6), Malavuwe (5) and Sambandou (6) from the 9th of July to the 21st of July 2022, surveying only 40 households due to the availability and willingness of respondents to participate in the pilot survey as this survey is not compulsory and respondents need to give out the consent. Table 3.1 shows the number of villages which were sampled for the pilot survey and the number of samples per village.

Table 3. 1: Villages surveyed for piloting and the number of samples per village.

Village	Catchment	No of samples
Siloam	Nzhelele	5/8
Khalavha	Nzhelele	18/13
Phadzima	Nzhelele	6/18
Malavuwe	Luvuvhu	5/12
Sambandou	Luvuvhu	6
		40/57

Pictures were taken during the pilot survey while both the researcher and research assistants were busy administering the questionnaire. This was done with the respondents' consent as it was first explained to them, and consent was granted. Figure 3.7 displays the pictures taken at Siloam, Sambandou, Phadzima, Malavuwe and Khalavha.

Figure 3.7: Pictures displaying the pilot survey from five villages that were surveyed (Source: Research Team)

3.7.2 Main household survey

A random questionnaire survey was used to select thirty (30) households per village to participate in the survey wherein only one adult member above the age of 18 was interviewed (Kothari, 2004) as a representative of the entire household. The researcher and ten research assistants interviewed the participants face-to-face using Tshivenda language to ensure that respondents understood the questions for proper response. The number of research assistants was increased due to the number of surveys administered for the main questionnaire survey. The average duration during the main survey was 1 hour or less due to the changes made to the questionnaires during pre-testing and getting used to the questions by research assistants. Overall, a total of 93 questionnaires were administered: Siloam (13); Khalavha (19); Phadzima (14); Malavuwe (9), Sambandou (18) and Tshakhuma (20), which is shown in Table 3.2.

Table 3.2: Villages surveyed for household survey and the number of samples per village

Village	Catchment	No of samples
Siloam	Nzhelele	13
Khalavha	Nzhelele	19
Phadzima	Nzhelele	14
Malavuwe	Luvuvhu	9
Sambandou	Luvuvhu	18
Tshakhuma	Luvuvhu	20
Total		93

As shown in Figure 3.8, some of the pictures were also taken during the main household questionnaire survey. Four of the six villages shown in Figure 3.3 are Khalavha, Tshakhuma, Tshakhuma and Malavuwe. Although consent was granted in the other two villages, pictures were not taken.

Figure 3.8: Household survey from all six villages that were surveyed.
(Source: Research Team)

3.7.3 Focus group discussions (FGDs)

The FGDs were conducted using an interview guide which was specifically made for FGD interview. This approach was used to obtain data from respondents purposely selected rather than randomly selected representative samples of a broader population. In this study, we reviewed the FGDs with 1 group per village of community leaders who have similar/common duties and experiences within the community. Thus, a group of community leaders were selected, including community councillors, Civic members and chiefs, therefore, in overall, a total number of six (6) groups were interviewed. The research team started with a brief explanation of the technique/method for all people present during the FGDs based on the structured questions. The number of people per group ranged from (6-20) participants, and the FDG interview lasted about 2-3 hours. Figure 3.9 shows some of the images taken during the FGD interview at Khalavha, Siloam, Phadzima and Sambandou, where people were gathered and asked questions collectively.

Figure 3.9: Pictures showing focused group discussions
(Source: Research Team)

3.7.4 Key Informant Interviews (KIIs)

The KIIs are designed to provide in-depth information from people, usually those identified as knowledgeable about a particular subject (William and Luloff 2006). According to Brody *et al.*

(2003), KII not only help research gather localized, culturally appropriate information but can also help build local collaborative support for further research and planning efforts and change processes when local information is considered and implemented.

An interview guide was collaboratively prepared, and participants were contacted by phone or email. Interview sessions were scheduled throughout October and November 2022. The interviews were semi-structured and conducted in both English and Tshivenda by the researcher and two research assistants. Interviews were done with participants from different fields who all had access to the communities at large. A total number of 6 KII's were done with people from the Department of Agriculture, Department of Water and Sanitation (DWS), Univen FM, Phalaphala FM and Vhembe District Municipality. Table 3.3 shows key informants who were interviewed and their knowledge of water, energy and food nexus. The KII are presented by broad categorisation which was made according to their social-institution responsibilities, roles, influence and decision capacity. People from different institutions or organisations were selected because they have first-hand knowledge about these communities and the issues and problems they face regarding water, energy, food or all of the nexus. Two different kinds of questionnaire tools were made; one was specially designed for those who are in the information and communication sectors.

Table 3.3: Resulting typology of engaged key informants

General category	Type of institution or organisation	Nexus knowledge area
Media	Phalaphala FM Univen FM	All All
Water management Organizations	DWS Water Affairs	Water Water
Agricultural organization	Vhembe Department of Agriculture and Forestry	Environment and Agricultural practices
Energy resource organization	Electricity Supply Commission (ESKOM)	Energy
Research and Development (R and D) Organizations	Vhembe District Municipality University of Venda	All Environmental science Botany and zoology

The questions asked were related to the themes they advance in relation to water, energy, food, sustainability and holistic programs in relation to the relationship between WEF and the programs that influence individuals and society to act on environmental issues and how they interact with communities. The second tool was done in institutions, wherein the community engaging plans, coordination mechanism with other sectors, communication channels, extensions on WEF technologies, factors influencing the adaptation of smart WEF technologies and what they suggest on WEF nexus solutions were determined. While some of the KIIs were done telephonically, Figure 3.10 shows pictures taken during KIIs at Univen FM, the Department of Agriculture and Eskom.

Figure 3.10: Pictures displaying the key informant's interviews
(Source: Research Team)

3.8 Data collection instruments and plan

Data were collected using a questionnaire (Appendix 1). The semi-structured questionnaire was developed based on a Mixed Research Approach, i.e. gathering of both quantitative (closed-ended questions) and qualitative (open-ended questions) data. The collection of quantitative data was necessary in order to test objective theories by examining the relationship among variables, which can be measured, and data analysis of numerical data is done by using statistical procedures and comes with a pre-defined report format (Creswell, 2014). Qualitative data is necessary to explore and understand the meaning that individuals or groups have about a certain social or human problem (Creswell, 2014). The qualitative approach collected data in the study setting, which involved gathering in-depth insights from participants. Thus, a Mixed Research Approach was necessary to take leverage on advantages and address limitations of both quantitative and qualitative approaches.

During this stage, key stakeholders who were active and participated in the assessment process were identified. A questionnaire was administered to collect information from the communities and relevant stakeholders on WEF resource access and use. Measures were taken to ensure that the representative sample selected for the interview had the same characteristics as those of the target population for generalisability.

3.9 Data analysis

Descriptive statistics were used to analyse data on innovations and practices identified by the respondents. The findings were triangulated through a key informant and focus group discussion findings. The data was analysed using IBM^{R} SPSS^{R} Statistics version 27 statistical package. Results were presented as Tables and Charts. Qualitative data were analysed using thematic analysis. Thematic data analysis involved identifying, analysing, and reporting patterns (themes) within data (Braun and Clarke 2006; Bryman 2016). Data analysis using

thematic analysis accords the researcher's flexibility and it fits different or multiple contexts. The study was able to compare its findings with the findings or conclusions drawn from other studies which would have been premised on the literature review from FGDs and KIIs.

3.10 Ethical considerations

Ethical issues emerge from value conflicts and conduct during the research process; thus, researchers must try to minimize risks to participants, colleagues and society while maximising the quality of information collected (Resnik, 2018; Iphofen, 2020). Ethics guide in development of accurate and verifiable knowledge without violating the rights and wellbeing of those who participate in research (Gillespie, 1995). Since the current study involved the volunteering of personal, confidential, and sensitive information, the major ethical concerns that were addressed by researchers included informed consent, voluntary participation, privacy and confidentiality, anonymity, and responsible conduct (Novak, 2014).

4 CHAPTER 4: ASSESSMENT AND MAPPING OF THE WEF NEXUS INNOVATIONS AND PRACTICES IN THE STUDY AREA

4.1 Overview of the WEF nexus innovations and practices

Innovations are central instruments of sustainability policies. Innovation covers a broad spectrum of dimensions across technological, institutional, behavioural changes, and responsive social, cultural and indigenous systems which in turn influence the effectiveness smart technologies such as carbon capture and storage initiatives (Steffen et al., 2018). Innovations thus encompass changes in processes, practices, structures and institutions at individual, organizational and technological level and at various spatial levels (Otto et al., 2020; Newell et al., 2021). Innovation is the embodiment, combination, or synthesis of knowledge in original; relevant; valued; and new products, processes, or services. Smart innovations in this regard refer to ideas or practices, new or existing that address WEF security risks (availability, cost, stability, access as well reduce environmental footprints). In a nutshell smart innovations have the potential or actual capability to contribute to economic, social, and environmental objectives of the current generations without compromising the needs of the future generation. Fundamentally, innovation has three levels: invention, implementation, and end product. All innovations begin with creative ideas implying they evolve from an existing idea or discovery of a new idea. Ideally, innovations involve successful implementation of creative ideas within an organization or community, processes, production of diverse and alternative goods (inputs) and services as well as the diffusion process in the delivery to the end user (Tohidi and Jabbari, 2012). Innovation is thus vital in the survival of a business and societal goals such as profit, productivity and adaptation to changing circumstances (Sengupta, 2014). Information accumulation can be considered as an innovation (Huffman, 2001). As Indigenous Knowledge System (IKS) is accumulated over time, it can be considered an innovation. Since the understanding of institutional-human behaviour interplay (Seto et al.,2016), is critical in overcoming lock-ins and fostering alternative innovative decarbonization trajectories (Buschmann and Oels, 2019), cross-sector linkages, and membership to community institution become critical part of innovation ecosystem as they both mediate capabilities and accumulation of knowledge and diffusion of ideas.

4.1.1 Climate Smart Agriculture (CSA) and food systems

Land use sectors and food systems have been identified as critical in the transition to carbon-neutral growth. Agriculture, Forestry and Land Use (AFOLU), which currently accounts for at least 23% of the global emissions have emerged as a focal sector for intervention. CSA is seen as a significant approach towards enhancing adaptation-resilience synergies and mitigation co-benefits (UNFCCC, 2021). CSA presupposes the integration of climate change into planning and implementation of sustainable agriculture practices. Since emission intensities are indicators of mitigation in agriculture (UNFCCC, 2016), it is adopted as a strategic vision in mainstreaming agricultural emissions into the climate action agenda. The adopted ecoefficiency or agriculture and energy use efficiency is the bench march for defining smart agriculture practices. This is in addition to profitability and resilience lenses. Hence, the CSA approach biases innovation towards greenhouse gas (GHG) emission mitigation to impact. Some of the food/ agriculture smart practices are highlighted below.

A. Conservation agriculture (CA)

CA is an agricultural resource use system that minimises resource input/ minimises loss of soil moisture principally by focussing on the minimisation of soil disturbance

- Include permanent zero tillage and soil cover (cover crops) to reduce moisture and increase carbon sequestration
- Reduces energy requirements for agricultural operations
- Reduced use of pesticides/ fertilizers due to better dynamics in the system
- Higher efficiency of inputs and better biodiversity in the long term leads to less pesticide/ fertilizer use compared with conventional production systems

B. Crop-livestock integration

Integrated livestock-agroforestry management practices which encompasses the combination of trees and/or legumes with livestock in an agricultural system having the potential to mitigate GHG, as well as capture and store carbon from the atmospheres.

C. One health achieved through

Food systems can help reduce and contain zoonotic disease outbreaks, improve food and water safety, and reduce anti-microbial resistance, benefitting human, animal, and environmental health. Important here is, improving waste and water management, with a focus on pollution from livestock and aquaculture, including zoonotic pathogens, antimicrobial residues and antimicrobial resistant bacteria and resistance genes.

D. Sustainable intensification

A process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land. The combination of the terms ‘sustainable’ and ‘intensification’ is an attempt to indicate that desirable outcomes around both more food and improved environmental goods and services could be achieved by a variety of means.

E. Precision agriculture

Precision agriculture (PA) is an approach to farm management that uses information technology (IT) to ensure that crops and soil receive exactly what they need for optimum health and productivity. The goal of PA is to ensure profitability, sustainability, and protection of the environment. It is critical as it assists in the choice of the right input and right amount, to the right place (placement), the Right time of application, and in the Right manner of use. It includes various forms of aquaponics, green house farming. These solve environmental challenges such as volatilisation, leaching and non-selective impacts of pesticides.

F. Rainwater harvesting

Rainwater harvesting is the simple process or technology used to conserve rainwater by collecting, storing, conveying and purifying of rainwater that runs off from rooftops, parks, roads, open grounds, etc. for later use.

G. Nature-based solutions

Nature-based solutions is the sustainable management and use of natural features and processes to tackle socio-environmental issues. These issues include climate change, water security, water pollution, food security, human health, biodiversity loss, and disaster risk management. It is there to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature.

4.1.2 Water smart practices and innovations

Water-smart approaches aim at developing alternative water sources as well as reducing losses through recycling and the use of sensors to reduce wastage. It cuts across the WEF resource nexus. For example, the use of drip irrigation and mulching in agriculture. Reducing the environmental footprint on water could be achieved through many means. These include developing alternative water sources, reducing losses, use of technology (smart metering as well as recycling).

4.1.3 Smart energy practices and innovations

Smart energy systems take an integrated holistic focus on diversification of energy sources (e.g. fossil fuels (coal, oil, and gas summed together), solar, and hydro) in the energy mix (electricity, heating, cooling, industry, buildings, and transportation) and allow for the

identification of more achievable and affordable solutions to the transformation into future renewable and sustainable energy solutions. Smart energy systems focus on the entire energy system in their approach to identifying suitable energy infrastructure designs and operation strategies that result in the most effective and least-cost solutions are to be found when each sub-sector is combined with the other sectors (Lund et al., 2017). At the household level, it includes the use of renewable energy sources such as solar, practices that reduce energy consumption and behavioural changes across the WEF resource nexus.

These are examples of smart innovations and practices which have multiple benefits to the users and beyond. It is in the context of these definitions and examples that the study assessed smart innovations and practices in the study area.

4.2 WEF nexus innovations and practices

According to Al-Saidi and Elagib (2017), there are three drivers behind the emergence of WEF thinking. These are (a) increasing resource interlinks due to growing scarcities, (b) recent resource supply crises, and (c) failures of sector-driven management strategies. The unprecedented surge in urbanization and population growth rates is generating multiple impacts, affecting WEF demands (Arthur et al., 2019). Moreover, the adverse effects are extending to climate, as well as to human and ecosystem health. Water, energy and food and nutrition securities are inextricably linked, with usage within one sector influencing the use and availability in the adjacent sectors. Therefore, coordinated efforts are often deemed critical to minimize trade-offs, while maximizing synergies among WEF sub-systems (Arthur et al., 2019). WEF nexus is about the interrelationships and trade-offs among system components including energy supply, electricity generation, water supply-demand, food production as well as mitigation of environmental impacts (Zhang and Vesselinov, 2017). Simpson and Jewitt (2019) explain it as “water for food and food for water, energy for water and water for energy, and food for energy and energy for food.” The nexus, if handled systematically, is viewed as a fresh way of thinking about related issues (Harwood, 2018).

4.2.1 Water sub-system

Water is used for extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing feedstock for biofuels and for generating electricity. Conversely, energy is needed for extracting, transporting, distributing and treating water. Additionally, energy fuels land preparation, fertilizer production, irrigation and the sowing, harvesting and transportation of crops. Food production further impacts the water sector through land degradation, changes in runoff, disruption of groundwater discharge, water quality and availability of water and land for other purposes such as natural habitat. The increased yields that have resulted from mechanization and other modern measures have come at a high energy price. Reducing both the impacts and drivers of climate change will require major shifts in the way we use and reuse South Africa’s limited water resources. Even though often overlooked, water resources are an essential part of the solution to climate change.

4.2.2 Food sub-system

In South Africa, agriculture is the largest water user at 61% of total water use, followed by municipal use at 27% (including industrial and commercial users provided from municipal systems), with power generation, mining and bulk industrial use, livestock and conservation and afforestation jointly making up the remaining 12% (DWA, 2013). The level of assurance at which agricultural water is supplied is lower than that of the other sectors (90%). Water for power generation is seen as strategically important and is provided with the highest assurance of supply (99.5%) (which translates to a 1: 200-year risk of failure). Interventions in the food sub-system consists of redesigning the food systems and promoting sustainable dietary patterns.

4.2.3 Energy sub-system

A significant amount of water is required to generate energy. Also, direct resource consumption in the food sub-system and indirect operations in the energy sub-system cause environmental impacts (Li and Ma, 2020). Inversely, water can also be an alternating source of energy through hydro-power. Energy security is defined as: “the uninterrupted availability of energy sources at an affordable price”. A collapse of energy systems could result in the disruption of food production, preservation and supply (Alawuyi, 2020). Greenhouse gas emission impacts WEF nexus management as well (Zhang and Vesselinov, 2017). Without water, we cannot produce food and energy; and without energy, we cannot process or distribute food and water (Alawuyi, 2020). The inextricable linkages between these critical domains require a suitably integrated and transformative approach to ensuring water and food security, and sustainable agriculture and energy production in South Africa. The nexus approach – an approach that considers the interactions, synergies and trade-offs of water, energy and food when undertaking the management of these resources can increase overall resource use efficiency, provide additional benefits and secure the human rights to water and food. The approach is a pathway towards achieving the 2030 global agenda on Sustainable Development Goals, particularly Goals 2 (zero hunger), 6 (clean water and sanitation), and 7 (affordable and clean energy). However, de Grenade et al (2016), pointed out that the WEF nexus fails to adequately acknowledge the environment as the set of natural processes underpinning the nexus, particularly interactions among water, energy, and food. The institutional framework governing the elements of the WEF Nexus is mostly fragmented.

4.3 Socio-economic background of households / participants

The background variables focused on the highest level of education, employment status, age in years, water sources and community water assets, sources of energy at a household level, and farm power resources and equipment,

4.3.1 Age, education, and employment

The classification of participants by age groupings revealed that 29% of the respondents were above 60 years of age, while only 13% were in the age grouping of 30 years or below (Table 4.1). Noteworthy, there was a fair representation of all age categories in the sample.

Table 4.1: Age group of respondents

		Frequency	**Percent**	Valid Percent	Cumulative Percent
Valid	21-30 yrs	5	12.5	12.5	12.5
	31-40 yrs	5	12.5	12.5	25.0
	41-50 yrs	3	7.5	7.5	32.5
	51-60 yrs	11	27.5	27.5	60.0
	Above 60 yrs	12	30.0	30.0	90.0
	Missing	4	10.0	10.0	100.0
	Total	40	100.0	100.0	
Missing	System	1	2.4		
Total		41	100.0		

The education levels of education of respondents are presented in Table 4.2 and Figure 4.1. This was necessary to determine the literacy level of participants. At least 46% of the respondents had secondary education, 14% had Technical and Vocational Education and Training (TVET) / College qualifications while about 3% had university education. Noteworthy the literacy level could be considered high given that only 10% of respondents had no schooling.

Table 4.2: Education level of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	N/A	1	2.4	2.4	2.4
	No schooling	4	9.8	9.8	12.2
	Primary education	5	12.2	12.2	24.4
	Secondary education	19	46.3	46.3	70.7
	TVET/College education	6	14.6	14.6	85.4
	University education	1	2.4	2.4	87.8
	Missing	5	12.2	12.2	100.0
	Total	41	100.0	100.0	

* N/A = not applicable

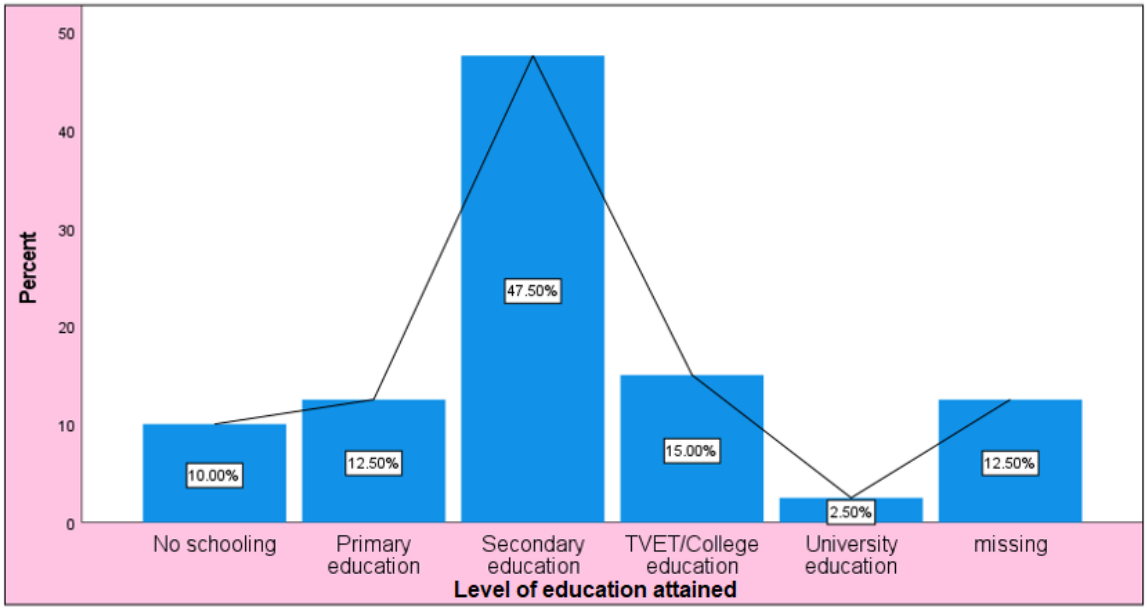


Figure 4.1: Level of education attained by respondents

With regard to employment status, at least 49% of the respondents had some form of employment and 39% were unemployed (Table 4.3). Of the employed participants,10% had formal employment whereas the other 36% were informally employed.

Table 4.3: Employment status of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	N/A	1	2.4	2.4	2.4
	Formal employment	4	9.8	9.8	12.2
	Informal (Self) employment	15	36.6	36.6	48.8
	Unemployed	16	39.0	39.0	87.8
	Missing	5	12.2	12.2	100.0
	Total	41	100.0	100.0	

* N/A = not applicable

4.3.2 Ownership of assets

Respondents had diverse community water resource assets with 20% obtaining water from the river source, 19% using community municipal taps, 15% using municipal taps within their households, and 12% using boreholes (Table 4.4). Moreover, the least source of water was 3% of respondents who uses community-owned waterpoint and the other 3% who uses springs, respectively.

Table 4.4: Water sources and community water assets

		Responses	
		N	Percent
Water Assets in the community	Source of water for household (HH)	18	27.7
	River as a source of water for HH	13	20.0
	Household uses communal municipal tap	12	18.5
	Household uses municipal tap within homestead	10	15.4
	Borehole as a source of water for HH	8	12.3
	Spring/fountain as a source of water for HH	2	3.1
	Community owned waterpoint	2	3.1
Total		65	100.0
a. Dichotomy group tabulated at value 1.			

All the respondents owned hand hoes which are the basic form of farm implements/ machinery, with about 5% owning ox-drawn ploughs (Table 4.5). A small proportion owned a tractor (3%) and bakkie (3%). It could suggest that most farmers either hire heavy farm machinery or only cultivate small farm sizes.

Table 4.5: Farm power resources and equipment

		Responses	
		N	Percent
Farm power resources[a]	Household owns Hand tools (fork, hoe, rake, spade)	33	89.2
	Household owns Tractor	1	2.7
	Household owns bakkie	1	2.7
	Household owns Ox drawn plough	2	5.4
Total		37	100.0
a. Dichotomy group tabulated at value 1.			

Regarding ownership of Information and Communication Technology (ICT), radio, Television and cell phone were the main tools of communication at the household level with newspapers only being read by about 1% of the households (Table 4.6). This has great significance on the dissemination of knowledge, especially climate-smart technologies.

Table 4.6: Ownership of ICT

		Responses	
		N	Percent
Ownership of ICT Assets	Owns Landline	5	4.6
	Owns Cell phone	34	31.2
	Owns TV	32	29.4
	Owns Radio	37	33.9
	Reads Newspaper	1	0.9
Total		109	100.0
a. Dichotomy group tabulated at value 1.			

4.3.3 Access to and use of WEF resources

South Africa is a water-scarce country with water resources critically impacting economic, political, and social welfare. The majority(50%) of the household had access to water resource within the household, 25% within 1 km while 25% beyond 1 km of the household (Table 4.7). However, the majority of the households either received water less than 3 times a month or never received it at all.

Table 4.7: Regularity in water access

Count		Furthest distance to main water source			Total
		Within the HH	Within 1 km of the HH	Beyond 1 km of the HH	
Regularity in water access	Daily	6	4	1	11
	Twice or less a week	3	2	0	5
	less than 3 times a month	3	1	4	8
	Never	7	1	3	11
	Unreliable to never	1	0	2	3
	More than 2 times a week	0	2	0	2
Total		20	10	10	40

Assessment was conducted to find correlation between water supply consistency and distance from a water source. These are symmetric measures. No significant relationship between distance to water source and consistency in the water supply. It implies that other factor other than distance account for the lack of significance (Table 4.8). From the FGDs, the factors that affect supply are constant breakage in water conveyance infrastructure and the long-time taken to repair as well as the abandonment of the water schemes such as boreholes once the pump breaks down as well as frequent load-shedding.

Table 4.8: Correlation between water supply consistency and distance from water source

		Value	Asymptotic Standard Error	Approximate T[b]	Approximate Significance
Interval by Interval	Pearson's R	.201	.130	1.268	.213[c]
Ordinal by Ordinal	Spearman Correlation	.172	.144	1.079	.287[c]
N of Valid Cases		40			
a. Not assuming the null hypothesis.					
b. Using the asymptotic standard error assuming the null hypothesis.					
c. Based on normal approximation.					

4.3.4 Food insecurity

About 54% of the respondents have not experienced all aspects of food insecurity while about 34% sometimes experience a form of food insecurity. About 13% of the respondents often experience food insecurity at all times (Table 4.9).

Table 4.9: Perception of food security at household level

		Responses	
		N	Percent
Perception on food insecurity at HH[a]	Often	41	12.9
	Sometimes	107	33.5
	Never	171	53.6
Total		319	100.0
a. Group			

Lack of water closely followed by lack of income at 28 and 26% respectively were perceived to be influencing food insecurity at the community level. With low agricultural production and theft closely flowing at 14% and 12% respectively (Table 4.10). All other causes such as health were not given prominence. This could be due to the low number of respondents but the statistics could change in the subsequent analysis as the sample size increases.

Table 4.10: Perception of causes of food insecurity at community level

		Responses	
		N	Percent
Perceived cause of food insecurity at HH	Low agricultural production	6	14.0
	Post-harvest Losses	4	8.0
	Lack/inadequate income	13	26.0
	Lack of water	14	28.0
	Lack of cooking energy	1	2.0
	Drought as reason	5	10.0
	Theft	6	12.0
Total		50	100.0

4.4 Identified WEF nexus innovations and practices in Vhembe District

This involved identifying and quantifying the WEF nexus smart technologies, innovations, and practices in the study area. In this case, the use of the concept of "technologies" is inclusive of innovations and practice. This involved fieldwork, surveys, and observations to collect water, energy and food resource data. In the project methodology, focus group discussions (with project stakeholders) and expert interviews (with WEF experts and development practitioners) with relevant stakeholders were used to select candidate WEF technologies before they can be recommended to the testing stage. Co-creation of solutions was the underpinning principle. The main output from this main activity is a refined list of promising WEF nexus technologies relevant to the Nzhelele and Luvuvhu River Catchment Areas from the co-created typology of promising technologies. There will be a Report on the results of the innovation platforms (i.e. convened for co-development of catchment area solutions) as a deliverable. Noteworthy, the study is limited to identifying and recommending these promising technologies and not implementation thereof at this stage.

4.4.1 Water innovations and practices

Figure 4.2 shows some of the water innovations and practices found in the study area. Reducing environmental footprint on water could be achieved through many means. These include developing alternative water sources, reducing losses, use of technology, smart metering as well as recycling. Generally, there was low use of water-smart technologies at the community/household level with harvesting and use of rainwater for irrigation and household use being the most prominent approach at about 32% (Table 4.11).

Table 4.11: Water use innovations

		Responses	
		N	**Percent**
Water use innovations[a]	Uses rainwater for irrigation	11	34.4
	Water recycling	10	31.3
	Water loss action	5	15.6
	Eses Drip irrigation	6	18.8
Total		32	100.0
a. Dichotomy group tabulated at value 1.			

(A) Rainwater harvesting in Tshakhuma

(B) Locket and protected borehole at Khalavha

(C) Hand pump borehole at Siloam Village

Figure 4.2: Water innovations and practices found in the study area (Source: Research Team)

Other than rainwater sources, about 60% of the household had access to tap water (with about 27% of these being within the household and about 33 being communal tap), with boreholes constituting about 22% of water sources for the respondents (Table 4.12).

Table 4.12: Water sources for the community by type

		Responses	
		N	**Percent**
Water Resources available at Household[a]	Household (HH) uses municipal tap within homestead	10	21.3
	Household uses communal municipal tap	12	25.5
	River as source of water for HH	13	27.7
	Borehole as source of water for HH	8	17.0
	Spring/ fountain as source of water for HH	2	4.3
	Community owned waterpoint	2	4.3
Total		47	100.0

Curiously most households(43%) used Jik as the water treatment method. About 52% of the households did not treat the water. Only 3% used other modern method such as filtration chambers (Fig. 4.3).

Table 13 presents some of the water innovations and practices found in the study. The table also gives uses for and challenges of using the innovations. The details in the table were provided by the respondents during interviews.

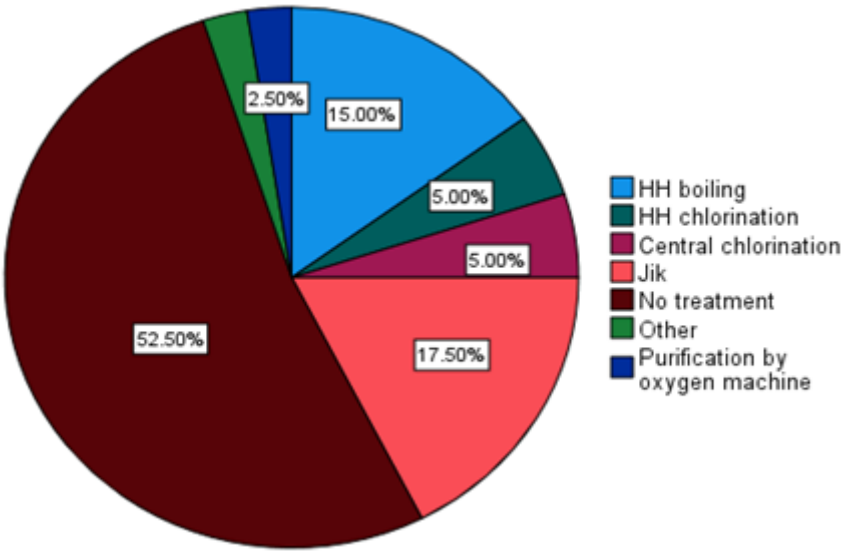


Figure 4.3: Water treatment practices for households

Table 4.13: Some of the water innovations and practices in the study area

	Rainwater	Groundwater	Water recycling	Water loss reduction
Type of innovation technology used	Roof harvesting	Generator	Grey water	Cover
		Hand drawn		Monitoring and reporting
		Motorised		
Uses of innovation technology	Domestic	Domestic	Irrigation Sanitation	
	Irrigation			
	Sanitation			
Reasons for using innovation technology	Cheap	Frequent drought	Water scarcity	Water scarcity (Saving available water)
	Easy to use			
	Frequent drought	Unreliability of municipal supply	Unreliability of municipal supply	
	Unreliability of municipal supply			
	Water saving	Only Source available	Water saving	
	Far from Source			
Challenges	High initial cost	High initial costs	Unsustainable for irrigation	Lack of knowledge
	Unsustainable roof			
	Unsustainable for use	High maintenance costs	Not enough water	
	Limited storage			None
	Low quality	Health problems	None	
	None			

4.4.2 Energy innovations and practices

Though there are other innovations, such as sun drying are common in the community, this section mainly focuses on mains electricity and solar and their uses. Increasing the use of biomass also emerged as an economic innovation in the context of load shedding and increasing cost of electricity. Figure 4.4 presents energy innovations at household level. Solar energy is used for heating and pumping water for irrigation.

(A) Paraffin stove

(B) Solar panel on a roof

(C) Biomass fuel

Figure 4.4: Energy innovations and practices found in the study area
(Source: Research Team)

The specific uses of electricity at the household level are given in the previous section on socio-economic background variables. Lighting, cooking and refrigeration are the main uses followed by other appliances (charging). Heating and cooling took less of the use for mains electricity. Sun drying, an indigenous method was used by about 13% of the households. Further, during FGDs, the community captured other methods such as smoking, salting and fermentation of food products such as milk (Table 4.14).

Table 4.14: Energy uses at households

		Responses	
		N	**Percent**
Uses of energy by category[a]	Heating	18	9.9
	Lighting	35	19.3
	Cooking	36	19.9
	Cooling	5	2.8
	Refrigeration/Freezer	28	15.5
	TV/Radio	27	14.9
	Uses energy for appliances	32	17.7
Total		181	100.0
a. Dichotomy group tabulated at value 1.			

The main grid electricity was used by about 98% of the respondents with biomass coming at about 44% of the respondents. Only about 11% of the households used solar energy (Table 4.15).

Table 4.15: Energy mix at household

		Responses	
		N	**Percent**
Energy Mix at household level[a]	Mains electricity as energy mix	38	60.3
	Biomass as energy mix at household	17	27.0
	Solar as energy mix at household	4	6.3
	LPG as energy mix at household	2	3.2
	Paraffin as energy mix at household	2	3.2
Total		63	100.0
a. Dichotomy group tabulated at value 1.			

About 10% of the respondents used solar energy (Table 4.16). Most households stated that they were not aware of solar energy as an alternative. Some of the challenges they faced in

using solar include theft of solar panels, and the high initial cost for low investment into solar energy. However, for those using it, they could identify its utility in terms of reliable energy supply especially for lighting and powering of TV/ Radios. Most FGD suggested Solar as one of the potential solutions to frequent load shedding in the community.

Table 4.16: Solar as energy mix at households

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	36	90.0	90.0	90.0
	Yes	4	10.0	10.0	100.0
	Total	40	100.0	100.0	

The main uses for solar in the community were lighting, television (TV) and accessories. However, most households stated that there was lack of knowledge on required capacity to meet their needs (Table 4.17).

Table 4.17: Specific uses of solar energy

		Responses	
		N	Percent
Specific uses of solar[a]	Energy used for cooking	17	16.3
	Energy used for heating	10	9.6
	Energy used for lighting	32	30.8
	Energy used for TV	25	24.0
	Energy used for accessories	20	19.2
Total		104	100.0

Table 4.18 and 4.19 present some of the energy innovations and practices found in the study. The table also gives uses for and challenges of using the innovations. As indicated before, the details in the table were provided by the respondents during interviews.

Table 4.18: Some of the energy innovations and practices in the study area

	Coal	Electricity	Firewood	Paraffin
Uses of innovation technology	Heating	Lightning	Heating	Lightning
		Cooking	Cooking	Cooking
		Refrigeration	Missing	Heating
Reasons for using innovation technology	Cheap	High cost of alternative	High cost of alternative	Easily available
		Easily available	Easily available	Cheap
		Cheap	Cheap	Loadshedding
		Convenient	Loadshedding	
		Lock ins (modern, only source, culture,)	Convenient	
			Reliable	
		Missing	Missing	
Challenge(s)	Pollution	Cost	Pollution	Pollution
		Lack of awareness	Bulkiness	
			Cost	
			Lack of awareness	None
		Loadshedding	Distance to source	
		It is dangerous	Easy to use	
		None	Not user friendly on rainy days	
		Missing	None	
			Missing	
	Missing	Missing	Missing	

Table 4.19: Some of the energy innovations and practices in the study area (cont'd)

	Solar	Biogas
Uses of innovation technology	Lighting	Lightning
	Charging accessories	Cooking
	Heating	
Reasons for using innovation technology	High-cost alternative	High-cost alternative
	Easily available	
	Cheap	Convenient
	Convenient	
Challenge(s)	High initial cost	Pollution
	Weather constraints	
	None	Missing

4.4.3 Food / agriculture innovations and practices

One of the most prevalent agriculture smart innovations and practices was mulching (46%) at household levels. Other practices were to deliberately allow field crop to rest for a season before replanting (24%) and the use of livestock manure (nine percent). Figure 4.5 show some of the agriculture practices identified in the study area.

(A) Organic manure (B) Mulching (C) Bucket irrigation (D) Irrigation using hosepipe and watering can

Figure 4.5: Agriculture innovations and practices found in the study area (Source: Research Team)

Table 4.20 summarises some of the agriculture smart technologies practised in the community.

Table 4.20: Smart agriculture innovations and practices in the study area

		Responses	
		N	Percent
Smart Agriculture innovations and practices[a]	Practising zero tillage at HH	3	9.1
	Practising mulching at HH	15	45.5
	Uses livestock manure	3	9.1
	grow crop season after season without a fallow period between crops	3	9.1
	Deliberately allows field crops to rest for a season before replanting	8	24.2
	Grows agroforestry tree species for various uses such as windbreaks, feeding livestock	1	3.0
Total		33	100.0

The Pie chart gives storage methods used at the household level in the community level. At least 40% use fridge and or freezer as the most common method used by households (Figure 4.6). This was closely followed by sun drying. About 33% of the respondents did not use any

kind of preservation method. Fumigation, a chemical preservation method was mentioned by about 3% of the respondents and was an indigenous method of using ash against pest infestation for cereals/ pulses. Sun drying, an indigenous method was used by about 13% of the households. Further, during FGDs, the community captured other methods such as smoking, salting and fermentation of food products such as milk.

Table 4.21 presents some of the food/agriculture innovations and practices found in the study. The table also gives uses for and challenges of using the innovations. The details in the table were provided by the respondents during interviews.

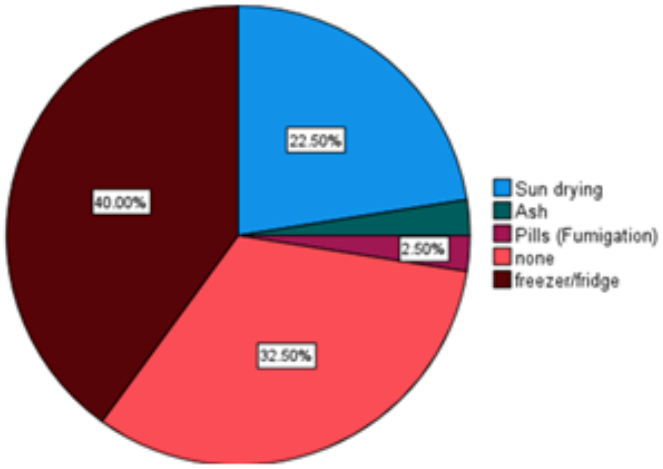


Figure 4.6: Food preservation methods

Table 4.21: Some of the food/agriculture innovations and practices in the study area

	Conservation agriculture (CA)	Smart irrigation (SI)	Sustainable intensification (SINT)	Disaster related insurance (DI)
Type of innovation technology used	Zero tillage	Drip irrigation	Relay cropping	Sin tax for crop damage from livestock
	Mulching	Sprinkles	Fallowing	N/A
	Manure	Buckets	Agroforestry	
			Organic practices	
Uses of innovation technology	Raised bed	N/A*	N/A	
	Double dug bed			
	Manure compost			
	Integrated Pest Management			
	No tillage			
Reasons for using innovation technology	Frequent drought (conserve soil moisture)	Reduced cost of irrigation	Reducing land size	Prevent conflicts amongst farmers
	Premium prices for production		Awareness on advantages	
	High cost of commercial inputs		Increasing costs of inputs	
	Concern for the Environment	Uses less Water	Soil fertility improvement	
	Replenish soil fertility.			
			Easier to use	
Challenges	High labour intensity	Blocking of nozzles	Difficult to use in drought seasons	Lack of awareness
	Pest		High labour intensity	

	Conservation agriculture (CA)	Smart irrigation (SI)	Sustainable intensification (SINT)	Disaster related insurance (DI)
	Costly	Labour intensive		
	None		Pests	
			None	

* N/A = not applicable

4.5 Adoption of the WEF nexus innovations and practices

4.5.1 Adoption of water innovations and practices

Water smart technologies either exploit alternative sources, reduce energy use in its exploitation or reduce cost. About 26% of the respondents named reliability, 21% finance, 17% cost saving and 12% value for the environment as the factors already influencing or likely to influence the adoption of water-smart technologies (Table 4.22).

Table 4.22: Factors influencing adoption of water smart technologies

		Responses	
		N	Percent
Adoption of water smart influencing[a]	Effect of finance	9	21.4
	Effect of lock-Ins	1	2.4
	Value for the environment	5	11.9
	Effect of social network	4	9.5
	Effect of peers	4	9.5
	Effect of family spillovers	1	2.4
	Effect of cost saving	7	16.7
	Effect of reliability	11	26.2
Total		42	100.0

In most cases, extra local institutions influence carbon transition visions or lock-ins (Sovacoola et al., 2020). Lock-ins in turn inform and justify the technological, institutional, policy and behavioural choices (Seto et al., 2016; Buschmann and Oels, 2019). The effect of lock-ins is thus multifaceted. First, it could undermine innovation and bias policy choices efforts on generic yet locally irrelevant alternatives. About 33% of the respondents identified initial costs with 20% for capital access and 20% for lock-ins respectively as significant barriers to water smart technologies (Table 4.23). Only about 7% viewed technical know-how and lack of alternatives while about 13% identified information as barriers to adoption of water-smart technologies.

Table 4.23: Barriers to adoption of water-smart technologies

		Responses		Percent Cases
		N	Percent	
Water Smart Tech Barriers[a]	Lack of alternatives	1	6.7	10.0
	Access to capital	3	20.0	30.0
	Initial cost	5	33.3	50.0
	Lock-ins	3	20.0	30.0
	Technical know-how	1	6.7	10.0
	Information	2	13.3	20.0
Total		15	100.0	150.0

4.5.2 Adoption of energy innovations and practices

Energy smart technologies reduce the costs and environmental footprint of each energy mix. Knowhow or knowledge and the potential effect on the reliability of energy source were more influencing or likely to influence the adoption of energy smart technologies at the household level by about 27% and 24% of the respondents respectively. Availability of finances and

cost saving at about 13% are also major factors influencing or likely to influence the adoption of energy smart technologies (Table 4.24).

Table 4.24: Factors affecting the adoption of energy-smart technologies

		Responses	
		N	Percent
Factors on adoption of smart energy[a]	Effect of knowledge	19	26.4
	Finance	9	12.5
	Lock-in	1	1.4
	Value for environment	6	8.3
	Effect social network	5	6.9
	Peers on adoption	3	4.2
	Family spillovers on	1	1.4
	Effect of market access	2	2.8
	Cost saving	9	12.5
	Effect of reliability	17	23.6
Total		72	100.0
a. Dichotomy group tabulated at value 1.			

About 78% of the respondents identified access to capital as the greatest barrier to energy-smart technologies with about 11% identifying information barriers and cost of alternatives as the barrier (Table 4.25).

Table 4.25: Barriers to adopting smart energy technologies

		Responses	
		N	Percent
Smart Energy Barriers[a]	Cost alternatives as a barrier to energy smart tech	1	11.1
	Access to capital as a barrier in energy smart tech	7	77.8
	Lack of information as a barrier in energy smart tech	1	11.1
Total		9	100.0
a. Dichotomy group tabulated at value 1.			

4.5.3 Adoption of food/agricultural innovations and practices

Smart Agriculture technologies such as composting, the use of manures, increase productivity, increase productivity and income, and also reduce greenhouse gas emissions Initial investment capital at about 34%; government policies at about 26%; capital and technical knowhow at about 15% each were the main factors stated by respondents as the most influencing or likely to influence the adoption of climate-smart agriculture technologies (Table 4.26).

Table 4.26: Factors influencing adoption of smart agriculture practices

		Responses	
		N	Percent
Adoption factors influencing smart Agriculture	Effect of initial cost	13	33.3
	Effect of technical knowhow	6	15.4
	Effect of gov regulation	10	25.6
	lack of information	3	7.7
	lack of capital	6	15.4
	lack of alternatives	1	2.6
Total		39	100.0
a. Dichotomy group tabulated at value 1.			

The community identified government policies/ regulations and laws as well as high initial cost as the greatest barriers to food smart/ land development initiatives. Among government policies, was a lack of extension and financing. Cost emerged as the most pressing barrier to agriculture smart technologies to 47% of the respondents. About 40% of the respondents cited government policies as the barrier while only about 13% gave technical know-how as the barrier (Table 4.27).

Table 4.27: Barriers to food/agriculture smart technologies

		Responses	
		N	Percent
Smart food technology barriers[a]	Policies as a barrier to adoption of food-smart technologies	6	40.0
	Technical know-how as a barrier to adoption of food-smart technologies	2	13.3
	Initial cost as a barrier to adoption of food-smart technologies	7	46.7
Total		15	100.0
a. Dichotomy group tabulated at value 1.			

The bar chart (Fig. 4.7) presents suggestions to improve food smart technologies. Providing subsidised inputs emerged as the topmost suggestion while increasing access to irrigation loans, credit, and loans also extension services emerged also other suggestions

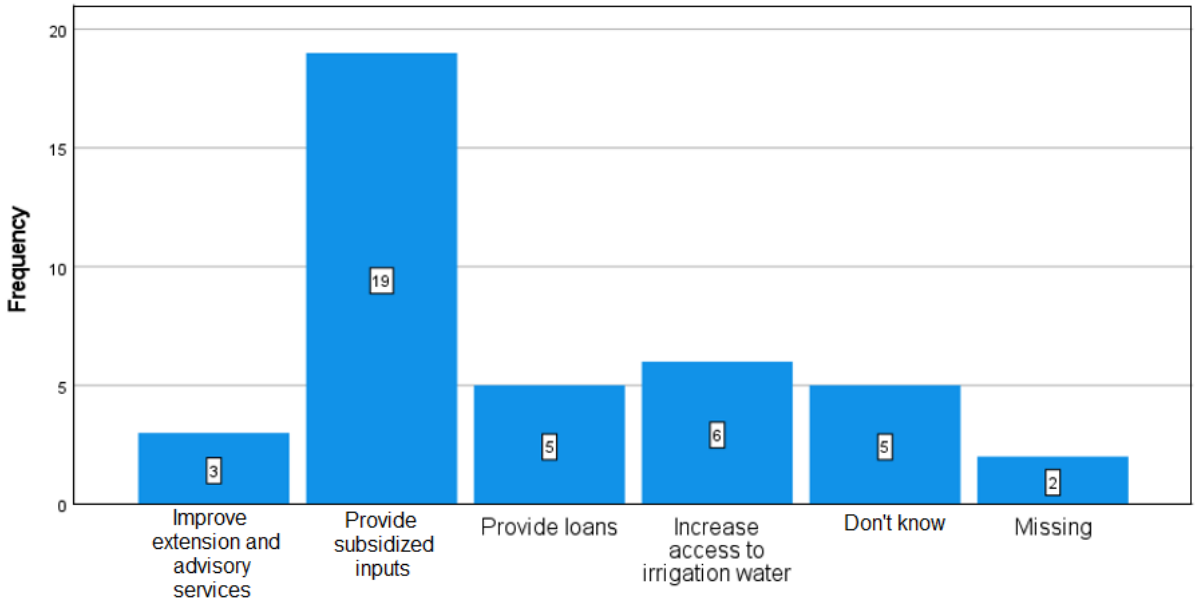


Figure 4.7: Suggestions to improve adoption of food-smart technologies

4.6 Identified indigenous knowledge system (IKS) and the WEF innovations

Broadening climate action areas with great potential for immediate scaling mitigation and closing of GHG emission gaps (IPCC, 2019; UNEP, 2019; Höhne et al., 2020) is increasingly being recognised in climate policy and focusing on indigenous IK for adaptation and mitigation of climate and WEF resource risks. This is closely tied to mainstreaming of local needs and aspirations in sustainability initiatives (Epstein et.al, 2015; Dapilah et al., 2020). Local contexts increasingly provide opportunities for learning, innovation, and transformation. IK is the institutionalized local knowledge built upon and passed on from one generation to another, usually by word of mouth and is the basis for resilience-building smart innovations. Incorporating IKS in planning can improve the adoption and scaling of climate-smart

agriculture innovations. Promoting climate-friendly policies at a community level is especially critical in reducing emission gaps (Bonner and Biglan, 2021).

The following are some of the indigenous innovations that were identified in the community.

- Winter-summer rotational cropping systems between vegetables and cereals (irrigated vegetables during winter to take advantage of ambient moisture and planting of cereals during summer to take advantage of relatively high rainfall amounts received
- Rainwater harvesting and its use for irrigation – reduce the environmental footprints of agricultural production systems on the environment
- Locally adapted breeds including indigenous cattle free-range piggery and poultry reduce the need for external inputs and/or the number of eternal inputs required
- Low external input Agriculture whereby there is minimal reliance on externally acquired inputs (inorganic fertilizers) but increased reliance on internal inputs such as manure and compositing among other nutrient recycling practices in the farming system. At household level these practices reduce costs(increase profitability), reduce emission footprint, as well increase resilience hence climate-smart agriculture.
- Conservation Agriculture including fallow strips, growing of agroforestry species
- Drip irrigation – substantially reduces the amount of water losses applied and losses through evapotranspiration
- Locally adapted crop varieties and livestock breeds – including short maturing crop varieties, drought tolerant crops such as sorghums and locally adapted cattle and pigs/ poultry
- Food preservation – sun drying as one of the ubiquitous technologies used in vegetable drying and preservation reduces the need for refrigeration
- Dryland Agriculture – including short maturing crop varieties, drought tolerant crops such as sorghums
- Water storage – rainwater harvesting is practised by the majority of the households reducing the pressure on conventional water extraction sources such as boreholes and tap water
- Non-convectional foods such as Mopani worms, and termites increase the resilience of communities to droughts/shocks as well as address environmental footprints along the value chain where the conventional food systems that require transport, refrigeration were to be relied on

4.7 Smartness of the identified innovations in Vhembe District

GHG emission footprint is a major indicator of innovation smartness and in turn depends on the quantity of resources consumed and pollution load into the environment. Energy efficiency (and/or wastages) take prominence in GHG emission footprint as it is the major driver in resource transformation. Figure 4.8 shows some of the smart technologies identified in the study area.

(A) Raised water tank for irrigation water as a contingency measure against loadshedding.

(B) *Luceana Leucocephala* is used as one of the agroforestry species in feed supplementation in both ruminants and non-ruminants, as well as used for soil fertility improvement.

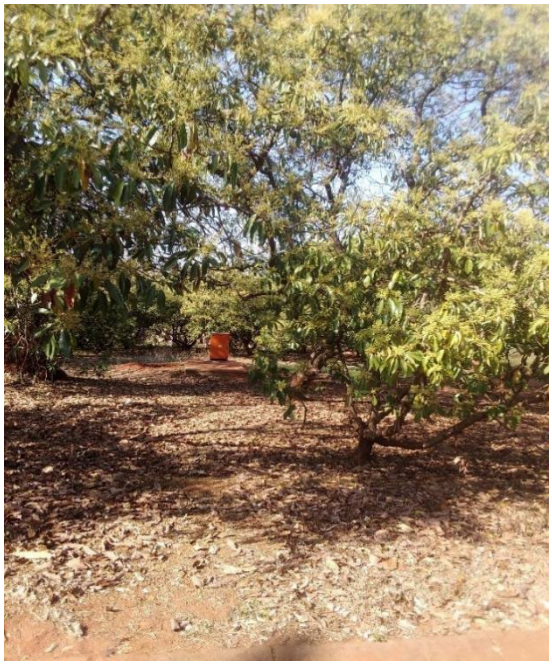
(C) Sprinkler irrigation equipment as one of the smart irrigation techniques relative to furrow irrigation

(D) Fallowing which also is a form of conservation agriculture

Figure 4.8: Some of the smart technologies identified in the study area
(Source: Research Team)

It was noted that the smartness of these innovations is related to water and energy saving.

Smart agricultural practices identified in the study area include avocado orchards which are some of the most common fruit trees and which perform multipurpose functions such as food, shade, and wind breaks. Figure 4.9 presents some of the smart agriculture practices identified in the community.



(A) Avocado orchards as one of the most common fruit trees and which performs multipurpose functions such as food, shade, and wind breaks

(B) Woodlots in the community provides multipurpose functions such as fodder, fuel, climate regulation

(C) Surface Irrigation in horticultural crops. Note the surface crusting/ cracking

(D) Orchards which perform multipurpose functions such as food, shade, wind breaks

Figure 4.9: Smart agriculture technologies identified in the study area at household level (Source: Research Team)

The criterion for smartness in our study thus includes perceived chain impact on the environmental footprints of identified WEF innovations and practices. The smartness is thus as follows.

- Minimised energy intensities in food, production and preservation using organic practices such as manuring and sun drying. The use of Solar pumps and panels for various uses such as lighting, cooking, charging accessories and pumping household water
- Reducing environmental footprint on water extraction through roof harvesting

- Increasing crop and water productivity through irrigation during winter while depending on rainfed agriculture to grow cereals during summer only reduces evapotranspiration losses and reduces the need for irrigation (hence extraction of water resources for irrigation)
- The use of local seed varieties and/ or short maturing cereals crops such as sorghum reduces the water footprint
- Diversification in agricultural enterprises including mixed farming that allows for exchange of nutrients to increase synergies and build resilience of the households
- Recycling of nutrients between livestock(poultry and cattle) and crops reduce need for external inputs hence contribute to sustainable agricultural value chains and food systems (reduce emissions of Green House gases as less transport of inputs and use of inorganic inputs)
- Regenerative agricultural practices such as CA reduce evapotranspiration
- Multiple purpose fruit trees reduce space needed for cultivation and substantially reduce the environmental footprint on water resources

4.8 Factors affecting adoption of WEF nexus innovations and practices

4.8.1 Financial support, extension for and adoption of WEF nexus practices

Financial access and inclusion as the key determinants in the adoption of technologies were assessed. The study respondents had low access to external financing of WEF activities. About 77% of the respondents did not have any form of financing with low financial inclusion and access impediment investment in sustainable water technologies. Some households (8%) relied on their savings/family remittances to invest in sustainable water practices. Of external financial resources, grants and cooperatives provided about 3% of the funds for investment in water development. The low financial access is reflected in the low adoption of water-smart technologies.

The same scenario is reflected in the energy sector where 90% of the respondents had not received any form of financial support. Family resources/savings provide 8% of the resources needed for investment in energy smart technologies such as solar followed by 2% from micro-credit. About 90% of the respondents did not have any form of financing for climate-smart agriculture. About 9% of the financing in climate-smart agriculture originated from family savings with grants only providing only 2% of the financing needs for climate-smart Agricultural practices. The remaining percentage (89%) did not have any source of finance.

4.8.2 Communication channels and extension services on WEF technologies

The technology adoption cycle (Rogers, 2004) aptly captures the diffusion process of innovations, practices and technologies. Access to information is one of the pathways that facilitate the uptake of ideas and closely resonates with human capital theory. According to human capital theory, the innovative ability is associated with information accumulation among other social economic factors (Huffmann, 2001). Communication channels are critical in the dissemination of information and their ultimate uptake. ICT applications have become very crucial tools in the WEF management sectors (Kappor, 2006). Though media for information communication such as radio, print, mobile phones, television and the internet are on the rise, their use and effectiveness depend on farmers' socio-economic attributes, such as educational level, as well as external determinants, i.e. cost of the technology.

Face-to-face, electronic and print media were noted in the dissemination of WEF technologies in the study area. Electronic media was the most ubiquitous communication channel, with radio topping at 32.7% of households. About 28.8% of the households owned TV sets.

Newspapers and journals were less likely to be used at 4.7%. Electronic media could thus be a critical channel and means for the dissemination of WEF technologies in the community.

4.8.3 Multiple players in WEF technology promotion and adoption

Multiple actors were active in the WEF sectors albeit at a low scale and uncoordinated manner. The segmented approach reduced synergies, reach and access to the technologies and innovations. Actors in energy promotion include those that promote solar energy (33.3%), energy-saving practices (33.3%), and other energy-smart technologies (33.3%). The main smart technology in energy was solar and energy-saving practices. In water, less than 9% of the respondents were accessing extension services on the promotion of smart water technologies. Actors in water promotion include water harvesting technologies (54.5%), water recycling and hydroponics (18.2% each) and drip irrigation practices (9.1%).

In agriculture, dissemination of smart-agriculture technologies was only for 14% of the total population surveyed, with manuring practices mentioned by 42.9% of the respondents. Other practices include cover crop (21.4%), climate manipulation (14.3%), mulching and zero tillage practices (7.1% each). It is worth noting that some of the technologies were cross-cutting and clearly show the interdependencies in the WEF nexus. However, several players in the WEF smart promotion seem to be acting in silos hence there is a lack of synergy.

4.9 Discussion, conclusions and recommendations

Reducing the negative impacts of WEF resources use on the environment has become a major concern in policy and practice since the 1987 Brundtland Commission. The focus has been on energy systems as they impact all resource use and environmental footprint. Mitigating the negative footprints requires practices and Innovations that reduce the environmental footprint and equally reduce cost, social equity or generally efficiency measures collectively referred to as smart WEF innovations. Agriculture, Forestry and Land use (AFOLU), which accounts for at least 23% of the global emissions (FAO, 2016a; FAO, 2016b; UNEP, 2019; IPCC, 2019) has emerged as a pivotal sector for intervention. Land use sectors (IPCC, 2019; Otto et al., 2020), and food systems in particular have been identified as critical in carbon transitions and capturing feedbacks (Aguilera et al., 2021). The whole agricultural production chain determines a direct and indirect energy demand through processes which spans any given agricultural value chain. These include land preparation, water extraction and use, use of agri inputs such as fertilizers, storage, Processing, and transportation of inputs and produce. The sources of energy and sustainable practices provide valuable option for decreasing energy demand per unit of agriculture input and pollution load into the environment.

Innovations and practices play a critical role to address the water, energy, and food challenges. The introduction of new and appropriate innovations and practices can improve resource efficiency in the water, energy, food sectors, and contribute to their security and sustainability. For instance, introducing renewable energy and improving energy efficiency, conservation agriculture, water recycling, and wastewater reuse are just few examples of such driving forces between the nexus of the three components and technology (Halalsheh et al., 2016). Such technological options and solutions are being implemented in South Africa, though to varying degrees, and are contributing to the efficiency of the utilization of these resources but need to be expanded to meet the attainment of mandates of both the nexus relevant SDGs and Paris Climate Summit of 2015. IK is critical in the Smart WEF innovation and practice as they hold the potential to reduce energy intensity and pollutant load into the environment.

Quantitative Story-telling (QST) approach is one of the newest approaches to the assessment of innovations with a strong nexus policy such as biofuels, shale gas, electric vehicles, and alternative water resources. By recognizing irreducible pluralism and uncertainties, QST inspects the relationships between the narratives used to frame sustainability issues and the evidence on those issues. From the current study, we have identified several innovations that

have the potential to reduce environmental footprint. These include seasonal cropping patterns, water use including rainwater harvesting, and multipurpose orchard patterns as use of drought-tolerant crops.

Since GHG footprints provide the metrics on carbon footprints and thus the smartness of a given WEF innovation and practice, there is increasing need to focus on the role of renewable energy. Equally, local-extra level institutions are critical in the advancement of WEF smart initiatives (Rasmussen et al., 2019; Dapilah et al., 2020). Lock-ins in turn inform and justify the technological, institutional, policy and behavioural choices (Seto et al., 2016; Buschmann and Oels, 2019) institutional lock-ins may constrain individual capacity to adopt management choices that positively impact smart innovations. The understanding of institutional-human behaviour interplay (Seto et al.,2016), is thus critical in overcoming lock-ins and fostering alternative innovative decarbonization trajectories such as renewable energy (Buschmann and Oels, 2019).

Sound selection of technology and proper policies across the nexus could ensure a holistic water, energy, and food security. Policy makers should be mindful of the fact that single sector efficiency may sometimes lead to a negative impact in the other two sectors, as in the case of water subsides in irrigation and the promotion of the use of solar pumps which both led to over-abstraction of groundwater. On the other hand, implementing WEF nexus innovations and practices, where two of, or the three components of the nexus are integrated as inputs to each other not only enhances resource efficiency, but also expands the available natural resource base and thus has an even more contribution to the sustainability and security of the three sectors (Halalsheh et al., 2016). IK Innovations and practices could play a critical role in innovation for resilience building around the WEF resources.

4.10 Conclusions and recommendations

4.10.1 Conclusion

The study identified Smart WEF innovations and practices in VDM. There exist several innovations and practices across the WEF resource sectors with IKS accounting for the majority of innovations and practices yet being accorded less attention. Mainstreaming IKS innovations and practices into the policy interventions could thus increase the suite of WEF smart innovations and practices and policy options for tackling the wicked sustainability challenges across scale. However, a life cycle assessment of particular innovations and practices may be required to quantify actual environmental footprints.

4.10.2 Recommendations

A holistic water, energy and food security system requires a detailed life cycle assessment evaluation impact assessment of the available suit of WEF innovations and practices alongside an assessment of policy and governance framework impacting them to evaluate the smartness of such innovations and thus inform policy on appropriate WEF smart interventions.

The innovations and practices found to be working within the local context and are promising should be taken to scale. The greater impact can be achieved through:

- “Scaling out”, which is about impacting greater numbers through replication and dissemination, increasing the number of people or communities impacted.
- Changing institutions, policy and law – “scaling up” to change the “rules of the game”.
- Strategies for “scaling deep” related to the notion that durable change has been achieved only when people’s hearts and minds, their values and cultural practices, and the quality of relationships they have, are transformed.

The initial stage was to identify innovations, technologies and practices at household and community levels. Therefore, there is a need to conduct transdisciplinary research to test and

validate the promising WEF nexus innovations, technologies and practices using co-creation approaches (including IKS).

5 CHAPTER 5: ROLES OF LEGISLATION, POLICY, GOVERNANCE AND INSTITUIONAL SYSTEMS IN IMPLEMENTATION OF THE WEF NEXUS APPROACH

5.1 Overview of legislation, policy, governance, and institutional dimensions

Managing WEF resources simultaneously while meeting several possibly competing objectives without jeopardizing any sector's resource base is complex (Orimoloye, 2022). To add to the complexity, other sectors such as economic, social, political, and environmental, as well as their effective implementation are influenced by the WEF nexus (Bizikova et al., 2013; Nhamo et al., 2020; Rosales-Asensio et al., 2020). The complexity needs to be addressed as soon as possible. Furthermore, the nexus framework has the potential to guide policy development and governance structures in a world facing climate change, population growth, and uneven access to resources (Simpson et al., 2020). Sustainable development requires distinct environmental, social and economic policies and integrated decision-making across all societal sectors (Nilsson et al., 2016).

Governance of the WEF nexus includes a diverse range of private and public systems that regulate the supply and demand of the nexus resources (Pahl-Wostl, 2017). Most residents regard providing access to improved water sources, sanitation facilities and electrification as an indicator of good governance and is reflected in both the Millennium Development Goals (MDGs) and SDGs (Simpson and Jewitt, 2019). Effective governance for the nexus occurs when the integration of resource sectors is actively pursued, such that synergies between water availability, energy generation and food production are enhanced (Benson et al., 2017). Koulouri and Mouraviev (2019) contend that the collaborative approach is one of the most impactful means of nexus governance, supported and promoted by effective relational equity management. Although there is an agreement that cross-sector collaboration and coordination are desirable, there is limited explanation of how coordination across sectors can be enabled (Weitz et al., 2017). Moreover, knowledge about the conditions for effective coordination of WEF biophysical interlinkages across sectors is lacking (Srigiri and Dombrowsky, 2021). Effective engagement of multiple stakeholders can address the challenges that arise from introducing an integrated approach to WEF policy design and implementation, increasing the potential benefits (Koulouri and Mouraviev, 2019).

The adoption of the nexus approach in policy design and implementation for the WEF sectors results in increased policy coherence, effective operationalisation and implementation of policy through appropriate governance instruments and institutions and a decrease in the impact of the most influential stakeholders/agents and their vested interests (Hoff and Ulrich, 2017). While policy and governance systems influence the implementation of the WEF nexus approach, it is observed that both policy and governance also benefit from implementing the nexus approach (Koulouri and Mouraviev, 2019). The main benefit of the nexus approach is that it enables the analysis of the complex and dynamic interrelations between the three sectors by lending a dynamic and holistic perspective and by promoting a multi-sectoral and multi-stakeholder collaborative engagement, involving governmental institutions/agencies, development organisations, funders, NGOs, local communities, business and industry, media, science-practice-policy interface and academics (Endo et al., 2017). Effective implementation of the nexus approach enables decision-makers to develop appropriate policies, strategies and investments, explore and exploit synergies, and identify and mitigate trade-offs between the development goals linked to water, energy and food and nutrition security (Hamdy et al., 2014).

Kim et al. (2015) reported that several studies have highlighted the significant roles of the WEF nexus, but institutional and policy directions of the nexus have received little attention. According to Jha (2021), local governance systems should be strengthened to improve well-being and build resilience in rural livelihoods. Jha (2021) further argues that embracing a cross-sector approach reduces the adverse impacts of policies on each WEF sector and that

policies need to become more inclusive and well-coordinated to support the implementation of the WEF nexus approach.

There is an imbalance in the way the WEF nexus plays out in the policy landscape in South Africa, in that the energy and water policies are developed in isolation without being interlinked (Gulati et al., 2013). For example, while the aspects of cost, carbon, and energy security have been given significant attention, water needs have not been ignored. Similarly, energy pricing has not formed part of the water pricing strategy for South Africa to date (Gulati et al., 2013). The study aims to contribute to policy and decision-making processes that will support the adoption of nexus innovations and practices and enhance the sustainability and resource security of each component system in the Nzhelele and Luvuvhu river catchment areas of the VDM in the Limpopo Province of South Africa.

5.2 Legislation, policies, and strategies/plans related to the WEF resources

South Africa has sectoral legislative pieces or acts, policies and strategies. Acts give a legal basis to a policy (Mudhara and Sezanje, 2020). A policy is a goal or an objective set by the government, which is aligned with the set laws or Acts (Kim et al., 2015). A strategy outlines the objectives, plans, guidelines, procedures and institutional arrangements required to achieve the desired goal (Mudhara and Sezanje, 2020). The identified pieces of legislation include the Constitution (No 108 of 1996), National Water Act (Act 36 of 1998), Conservation of Agricultural Resources Act (No 43 of 1983), Agricultural Research Act, 1990 (No. 86 of 1990), and National Energy Act (No 34 of 2008). The policies considered in this case include the National Water Policy (1997), the Policy on Agriculture in Sustainable Development, and the Energy Policy. The strategies considered include the National Water Resources Strategy (2013), Strategic Plan 2020-2025, Agriculture, Land Reform and Rural Development, Agriculture and Agro-Processing Master Plan 2022 (DALRRD, 2022), and Strategic Plan 2020-2025, Department of Mineral Resources and Energy.

5.3 Degree of support of legislation, policies, and strategies to the WEF nexus

An analysis of how national legislation, policies, and strategies in the WEF sectors support the WEF nexus approach was conducted. The analysis involved reviewing the sections and provisions of the legislation, policies and strategies in the water, energy, and agriculture sectors and assessing the degree of support each provides to the WEF nexus approach. The levels of degree of support considered in this analysis were strong, moderate, weak and none, based on the approach of the World Health Organisation (WHO) (WHO, 2019). Table 5.1 presents the results of the analysis on the degree of support of the legislation, policies and strategies for the WEF nexus in the country. The colour coding used is specific to this study.

The Constitution, in Section 27: (1) (b) (Republic of South Africa, 1996), guarantees every person the right to access “sufficient water and food”. The Constitution also has provisions for guaranteeing access to energy resources in the country. The National Water Act 36 of 1998 (Republic of South Africa, 1998a) sets the basic human needs of water for drinking and food preparation and personal hygiene. The Act also contains provisions for water use for food production under irrigated agriculture. Part 5 of the Act provides for regulating activities that negatively impact water resources, including altering flow regime as a result of power generation, and aquifer recharge using waste or water-containing waste. These are identified in the Act as controlled activities.

Table 5.1: Degree of support of legislation, policies, and strategies for the WEF nexus

Act/Policy/Strategy	Water	Energy	Agriculture
The Constitution (No. 108 of 1996)			
National Water Act (No. 36 of 1998)			
Water Services Act (No. 108 of 1997)			
The National Water Policy (1997)			
National Water Resources Strategy (2013)			
National Water Conservation and Demand Management Strategy 2004			
Conservation of Agricultural Resources Act (No. 43 of 1983)			
Agricultural Research Act, 1990 (No. 86 of 1990)			
Policy on Agriculture in Sustainable Development			
Strategic Plan 2020-2025, Agriculture, Land Reform and Rural Development			
Agriculture and Agro-Processing Master Plan 2022			
National Energy Act (No. 34 of 2008)			
Energy Policy			
National Energy Efficiency Strategy of the Republic of South Africa 2009			
Strategic Plan 2020-2025, Department of Mineral Resources and Energy			
Key: Strong	Moderate	Weak	None		

The main objects of the Water Services Act (No 36 of 1998) include providing for the right of access to basic water supply and sanitation necessary to secure an environment not harmful to human health or well-being, and the promotion of effective water resource management and conservation (Republic of South Africa, 1997a). The Act has provisions for the industrial use of water, including mining, manufacturing, generating electricity, land-based transport, and construction or any related purpose. This provision shows that the Act supports the developmental link between water and energy resources. There is, however, no mention of the use of water for agricultural purposes in all its provisions. It is known that urban agriculture plays an important role in promoting food security, hence the Act should make some provisions for promoting the water-food nexus.

The National Water Conservation and Demand Management Strategy (Department of Water Affairs and Forestry (DWAF), 2004) supported the water-energy nexus through power generation. According to the strategy, power generation provides the opportunity for water conservation through the use of dry cooling technology at power stations as it saves water. South Africa has demonstrated the ability to develop dry cooling power stations during periods of drought spells which should be promoted, regardless of any water availability status (DWAF, 2004). The strategy promoted equitable and efficient water use by providing regulatory support and an incentive framework that would improve irrigation efficiency and increase productivity. The strategy aimed to promote optimal water use to allow for the release of water to be utilised by new entrants in the agriculture and other water use sectors. This demonstrates that the strategy supported the WEF nexus approach in managing and developing the three resources.

The water policy states (Republic of South Africa, 1997b) that water resources cannot be managed in isolation from other natural resources. It is implicit from this that the policy recognizes the linkages among water, energy and food/agriculture among other resources.

However, there is no explicit reference to the development and management of water resources in accordance with the water-energy-food nexus approach. Energy is referred to in the Policy in relation to unconventional water sources, such as desalination, which requires large amounts of energy and is extremely expensive, but may relieve water stress. (Republic of South Africa, 1997b).

The National Water Resources Strategy (DWA, 2013) supports irrigated agriculture through the promotion of water-efficient irrigation systems. It also promotes financial support and water allocation to improve water-based rural livelihoods and food security for all. In this strategy, water plays a central role in most of the national planning initiatives including agricultural development, energy security, tourism and recreation, mining, industry and municipal water supply. The reliable supply of adequate quantities of water at the required quality is an essential input to economic growth and job creation. Power generation continues to be water use of strategic importance. Strategic water use is crucial to the national development outcomes and the economy as a whole, including the continuous availability of water for electricity generation throughout the country (DWA, 2013).

The objectives of the Conservation of Agricultural Resources Act (No 43 of 1983) are to provide for the conservation of the natural agricultural resources of the Republic by maintaining the production potential of land, combating and preventing erosion and weakening or destruction of the water sources, protection of vegetation and combating of weeds and invader plants (Republic of South Africa, 1983). The Agricultural Research Act (Republic of South Africa, 1990) does not mention research on water and energy resources as they link to agricultural production.

One of the strategic policy directions in the policy on agriculture in sustainable development is to empower communities to enable them to make informed decisions in meeting essential food, water and energy needs while conserving natural resources and environment. The policy contains elements that support the WEF nexus approach in agricultural development.

The agriculture strategic plan considered sustainable management of the country's natural resources (land, soil, water and climate systems) as important for their sustainable use and food security. While the strategy considered the management of water and agricultural resources as being critical to the country's socioeconomic development, it remained silent on the issues related to energy resources. The Strategic Plan 2020-2025 of Agriculture, Land Reform and Rural Development has identified opportunities to be explored, including sustainable agriculture, renewable energy for agriculture, alternative waste treatment, water usage efficiency and symbiosis programme mapping. The Agriculture and Agro-Processing Master Plan 2022 of the DALRRD does not mention the links of water and energy to agricultural production and processes (DALRRD, 2022).

In Section 6(2)(a), the National Energy Act (No 34 of 2008) provides for an integrated energy plan which takes into account plans related to transport, electricity, petroleum, water, trade, macro-economy energy infrastructure development, housing, air quality management, greenhouse gas mitigation within the energy sector and integrated development plans of local and provincial authorities (Republic of South Africa, 2008). The Act also provides for the contribution of energy supply to socio-economic development, which implicitly includes agriculture development.

The Energy Policy (Republic of South Africa, 1998b) includes the provision of efficient and affordable energy for traditional and commercial agricultural use and ensuring that commercial farmers have access to energy supplies and technologies. The policy focused on improving energy efficiency due to an increase in inputs for the same agricultural outputs (Republic of South Africa, 1998b). It also focused on improved energy services required for smallholder

agriculture as well as providing agricultural, forestry and agro-forestry products, by-products and residues as raw materials for biofuels.

Energy generated from water (waves, tides, waterfalls and rivers) will never be depleted as long as the water is available. South Africa has a mix of small hydroelectricity stations and pumped-water storage schemes (DMRE, 2020a). White papers in all of these areas have been, or are in the process of being, developed (Republic of South Africa, 1998b). The energy policy supports the development of the WEF resources integrated manner, which is the foundation of the WEF nexus approach.

The Integrated Resource Plan (IRP2019) of the Department of Mineral Resources and Energy (DMRE) (DMRE, 2019) was developed considering the water-energy nexus whereby recurring droughts threaten hydropower potential as climatic conditions change. Hence, the plan focused on the possibility of deploying energy technologies for purposes of desalination, provided they have low variable costs that would not render the desalination process unaffordable. The promulgated integrated resources plan 2010-2030 identified the preferred generation technology needed to meet expected demand growth up to 2030. The Strategic Plan 2020-2025 of the DMRE has included minimising water usage related to energy supply in its integrated resource plan (DMRE, 2020b). The plan also emphasized that cooperation between the DMRE, Department of Water and Sanitation (DWS) and Department of Environmental Affairs (DEA) will be encouraged towards implementing one environmental system.

The goals of the National Energy Efficiency Strategy of the Republic of South Africa of 2009 underscore the need to improve the health of the nation, create jobs, alleviate energy poverty, minimise environmental pollution and CO_2 emissions, improve industrial competitiveness, improve energy security, and minimize the necessity for additional power generation capacity (Republic of South Africa, 2009). There was no mention in the strategy of the links of energy development to water and agricultural development, an indication of the lack of support for the WEF nexus approach in the energy strategy.

The integrated energy planning of the DMRE (2020b) seeks to consider all the key elements of the energy value chain. The energy end-users in the value chain include households and irrigation pumping, and the demand for energy includes energy for residential, agricultural, and transport sectors (Fig. 5.1).

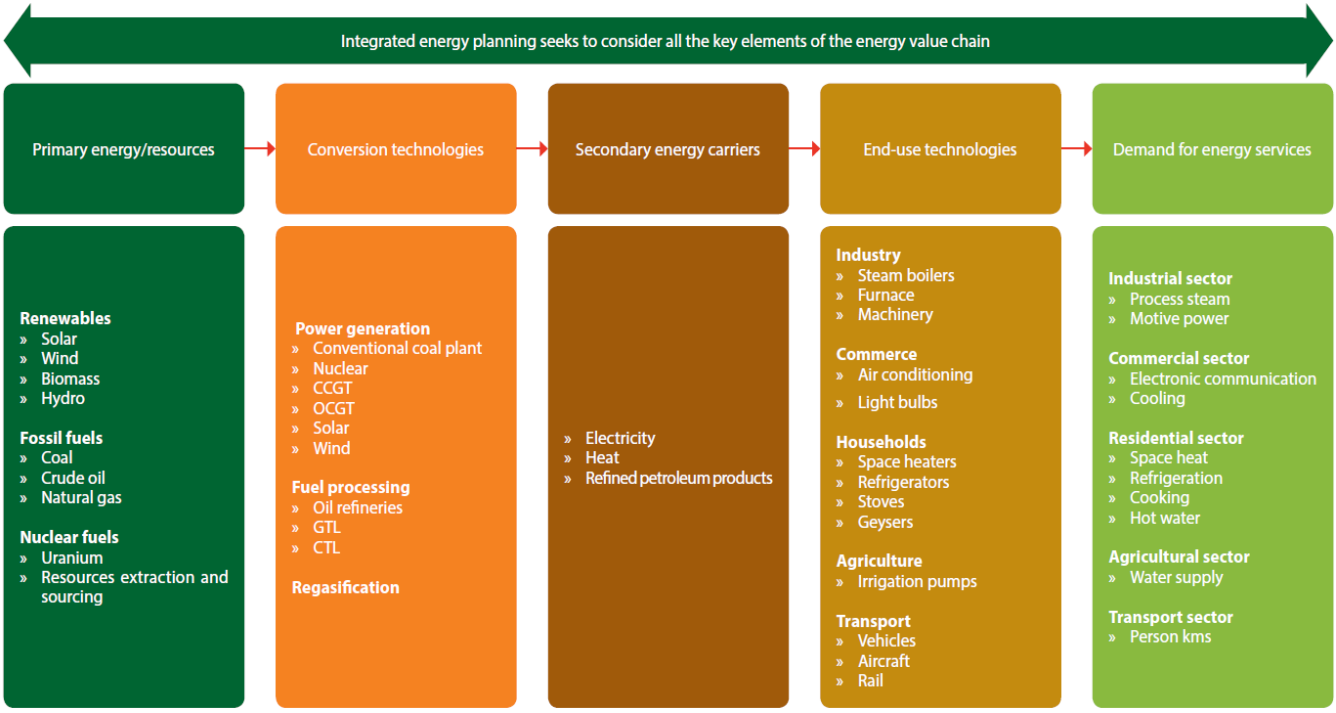


Figure 5.1: The energy value chain
(Source: DMRE, 2020b)

The plan also takes into account that human activities including agriculture, energy consumption and mining, amongst others, exert pressure on the earth, hence the need for integrated development of these resources. The energy plan had a strong linkage with water resources use and development and a strong reference to linkages of energy resources to agricultural development and production.

5.4 Governance and institutional dimensions of the WEF nexus

5.4.1 Governance systems and institutions in the study area

The governance of the WEF nexus system assessed in this study included private and public systems that control the supply and demand of water, energy and food, and that provide access to improved water sources, sanitation facilities and electrification. In this case, the study considered the national, provincial, local and community governance actors and institutions.

The institutional arrangements for water governance are presented in Figure 5.2. The Minister of Water and Sanitation has the overall responsibility for effective water management as the custodian of the indivisible national water resource. This responsibility is discharged through the DWS which is also responsible for overseeing the overall implementation of the Act (DWA, 2013). The Act also allows for the Catchment Management Agencies (CMAs) whose role is water management at a water management area/catchment level and is responsible for the progressive development of catchment management strategies. The Act also states that the CMAs will use the catchment management strategy consistent with the National Water Resource Strategy (NWRS), within its water management area. It is important to note that most of this responsibility is delegated by the Minister.

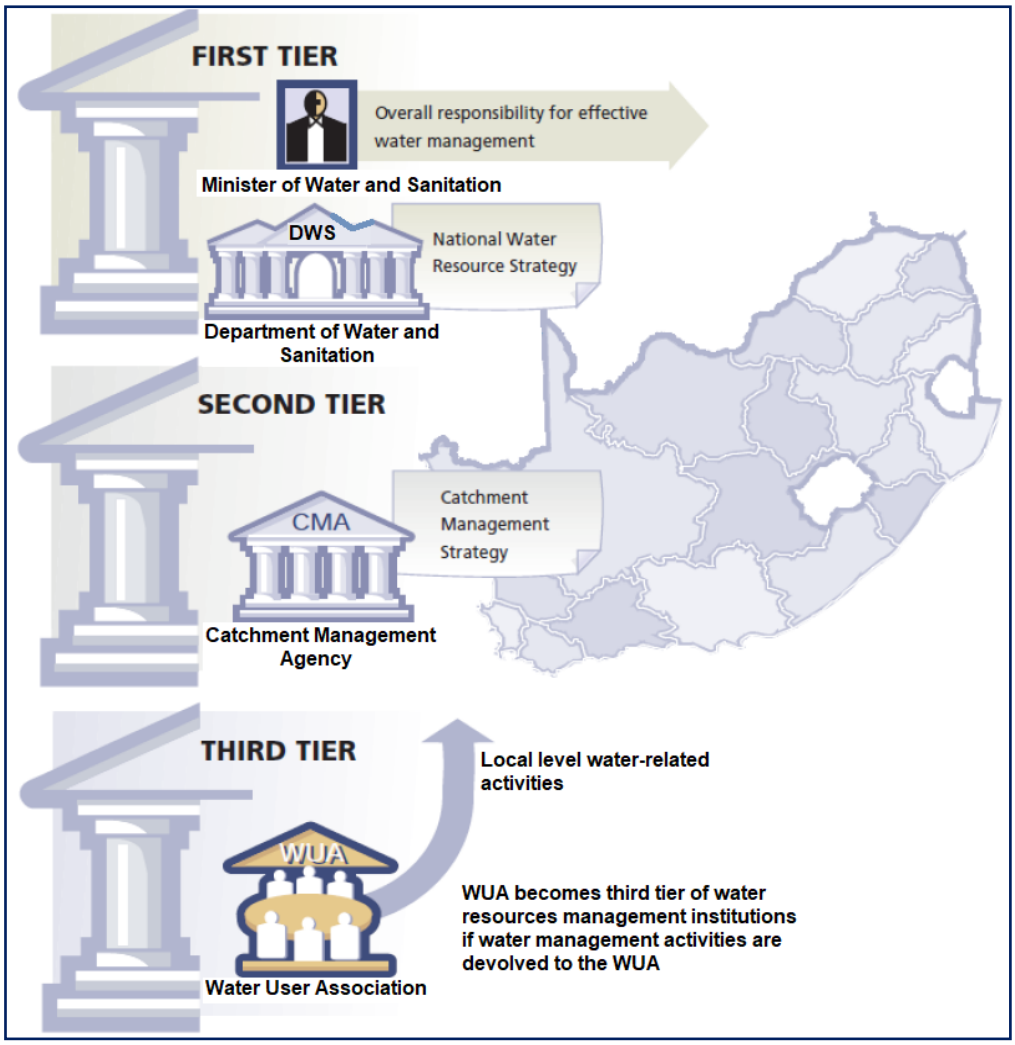


Figure 5.2: Institutional arrangements for governing water
(Source: DWA, 2013)

The third tier in this framework is considered to operate at a local level lower than the water management area (WMA). The concept of local water resource management is based on the internationally accepted principles of Integrated Water Resource Management (IWRM), which requires the involvement of resource users in the implementation of water resources management. This proposition was also supported by the White Paper of 1997 which highlighted the role that Irrigation Boards (IBs) and Water Users Associations (WUAs) play at this level (DWA, 2013). Accordingly, IBs and WUAs have continued to discharge functions related to this objective as well as those delegated to it by the Minister. Since the promulgation of the Act; these institutions have played crucial roles in managing water supply or distribution to various water users based on their water demands and license schedules. This suggests that IBs and WUAs are critical institutions in developing and implementing water demand management programs and initiatives at the local level, especially within the agriculture sector. WUAs generally perform and manage the operational, bulk raw water supply, resource management and representation functions.

Energy is crucial in human activities and an economy's social and economic development. One of the key aims of the DMRE is to ensure energy security, aimed at ensuring the availability of energy resources and access to energy services in an affordable and sustainable manner while minimizing the associated negative impacts of its use. The energy sector is then governed through the interaction of government, regulatory, and industry stakeholders, as depicted in Figure 5.3.

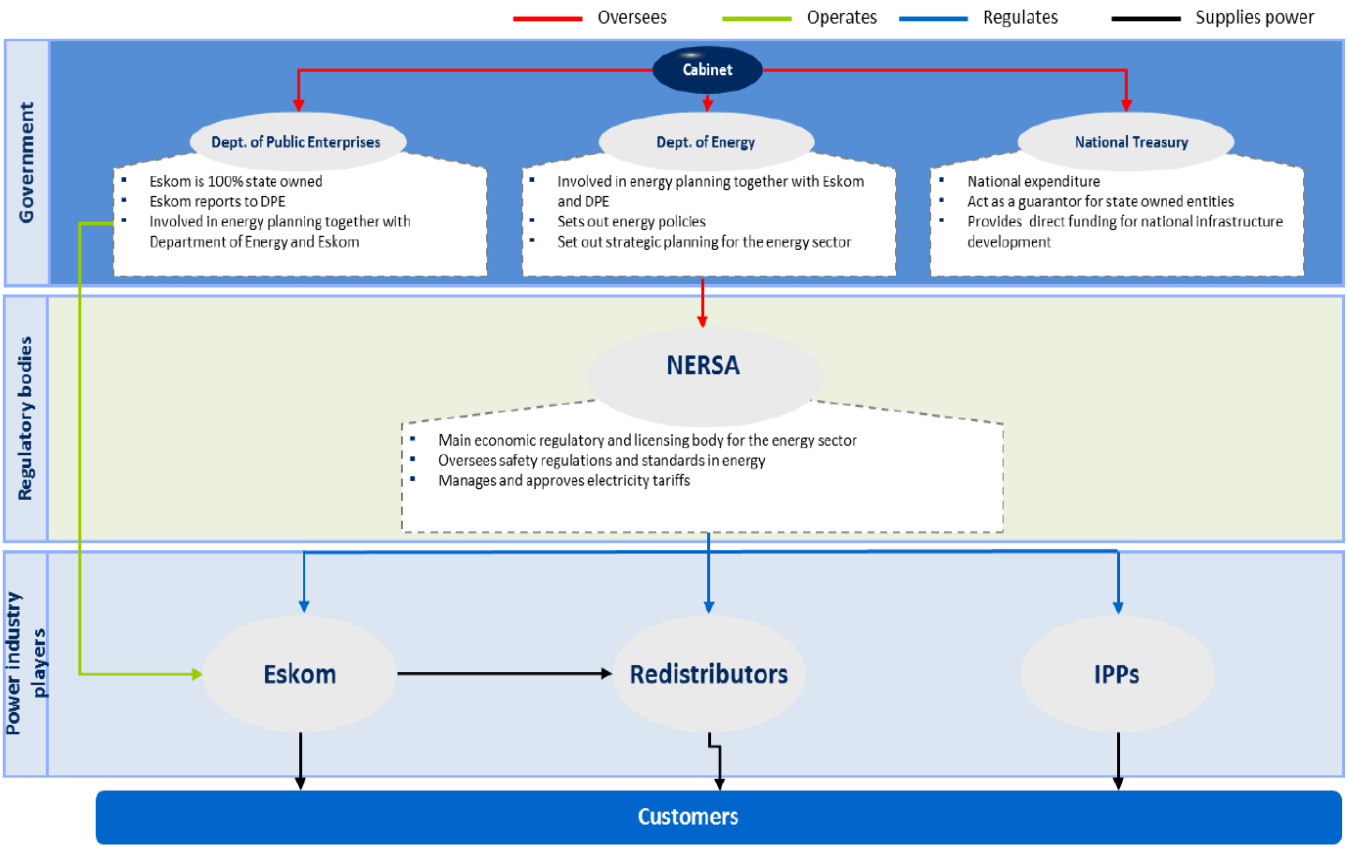


Figure 5.3: Energy governance landscape
(Source: Meko, 2015)

Power industry players include the state-owned utility Eskom, which accounts for more than 90% of the country's power generation capacity. Most redistributors are municipalities that buy electricity from Eskom and resell it to the end consumer. Presently most Independent Power Producers (IPPs) are in the renewable energy space. The process of energy policy development is overseen by the Department of Energy (DoE) in consultation with relevant stakeholders to ensure inclusivity. The DoE mainly undertakes government oversight, the Department of Public Enterprise (DPE), and the National Treasury. Energy sector regulation and licensing is the responsibility of the National Energy Regulator of South Africa (NERSA), which plays a critical role in supporting that government energy objectives are met.

The energy governance can also be assessed by considering the three subsectors of the electricity infrastructure: generation, transmission and distribution. Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers in South Africa. It also distributes electricity to municipalities, who in turn redistribute electricity to businesses and households within their areas. Eskom also purchases electricity from IPPs in accordance with various agreement schemes and electricity-generating facilities out of the country (DMRE, 2019).

5.4.2 Governance actors and their roles

This section presents the main governance actors and their roles in the WEF sectors as identified by the interview respondents. The identified main governance actors and their roles in the water sector are presented in Tables 5.2 and 5.3, respectively.

Table 5.2: Governance actors in the water sector

Governance Actor*		Frequency	Percent	Cumulative Percent
Valid	CBO/NGO/CSO	4	3.1	3.1
	Supplier	3	2.3	5.5
	Don't know	105	82.0	87.5
	Municipality	10	7.8	95.3
	Government	1	0.8	96.1
	Dept. of Water and Sanitation	5	3.9	100.
	Total	128	100.0	

* CBO = Community-based Organization; NGO = Non-Governmental Organization; CSO = Civil Society Organization

The results in Table 5.2 show that knowledge of governance actors among the respondents was too low at 18%. The low level of knowledge of governance actors poses a serious challenge to sustainability, enforcement of rules and regulations, and governance interventions. The municipality was the most mentioned governance actor at 8% followed by 4% for the Department of Water and Sanitation. Non-government actors were mentioned by 3% of the respondents.

Water supply and conveyance were the most mentioned at 8.6% followed by regulatory measures through licencing and permits (5.5%). Most of the respondents (82%) didn't know the roles played by the governance actors in the water sector. The least mentioned actors were advocacy and conflict resolution (1.6% each) followed by capacity building (0.8%), and yet these are critical areas in the governance of water resources. The results show that while the various water governance actors may have various roles designated to them, the impacts of these roles on the communities appear not to be very significant.

The identified main governance actors and their roles in the energy sector are presented in Table 5.3. Eskom was named as the key player in the energy sector by about 53% of the respondents, while 42% of the respondents did not know of any actor in the energy sector. Non-state actors were only named by 5% of the respondents. Most respondents' recognition of Eskom as the main actor ranks high among all the WEF sectors. This probably is due to the centrality of electricity in the social economic well-being of the communities surveyed and the nation at large. The roles of government actors in the energy sector were investigated. Energy supply and regulatory roles were the most mentioned at 22% and 15%, respectively, while 63% of the respondents didn't know the roles played by the governance actors in the energy sector. Advocacy and training/awareness creation were mentioned at 1% each, and yet these are critical areas in the governance of energy resources.

Table 5.3: Governance actors in the energy sector

Governance Actor*		Frequency	Percent	Cumulative Percent
Valid	Don't know	54	42.2	42.2
	Eskom	68	53.1	95.3
	CBO/NGO/CSO	6	4.7	100.0
	Total	128	100.0	

* CBO = Community-based Organization; NGO = Non-Governmental Organization; CSO = Civil Society Organization

Table 5.4 presents the respondents' views of the governance actors in the food production sector. Agriculture activities and extension play acritical roles in social economic development, particularly rural development. However, 70% of the respondents were not aware of any governance actors in the agriculture sector. This is corroborated by low extension services access. About 23% of the respondents recognised the Department of Agriculture/government as the key actor in the food production sector, while less than 1% named the municipality as an actor in the food sector.

Table 5.4: Governance actors in the food/agriculture sector

Governance Actor*		Frequency	Percent	Cumulative Percent
Valid	Don't know	89	70.2	70.2
	NGO/CBO/CSO	7	5.5	75.7
	Department of Agriculture	31	22.6	96.3
	Municipality	1	0.8	100.0
	Total	128	100.0	

* CBO = Community-based Organization; NGO = Non-Governmental Organization; CSO = Civil Society Organization

Informal and formal institutions form a critical part of the governance of WEF resources. Both local and extra-local institutions influence the performance of WEF institutions. Only 34% of the respondents belonged to any form of the institution of collective action. Of these, only 14% belonged to the WUA, 21% to the Savings and Credit Cooperative Organization (SACCO) scheme, 2.3% with microcredit financing and 63% as members of an interest group.

5.5 Governance challenges and opportunities

5.5.1 Governance challenges

Effective governance interventions can only respond to expressed needs and concerns. In water, 60% of the respondents felt that domestic (potable) water was of concern to the community. A myriad of issues around water resources included cut-offs, non-repair of damaged infrastructure and contamination of water sources. Of these, 3% further felt that use rights were not well addressed due to permitting requirements. Other concerns included irrigation water (31.6%) and the dimension of user rights for irrigation water (5.1%).

Governance concerns in the energy sector included access to non-renewable energy (41.7%) and renewable energy (38%). Of these, 14.8% strongly expressed their concern about the permitting requirements on solar installation, which they felt undermined access to alternative energy sources, especially amidst crippling load-shedding schedules currently being experienced. This is in addition to the high cost of initial installation. Lastly, user rights concerns about non-renewable energy accounted for 5.6%. Concerning the food sector, the majority of the respondents (79%) felt access to land for food production was a major governance concern that needs to be addressed. Others (20.8%) mentioned the user rights for irrigation water as a governance concern.

One of the main factors which affect the governance of WEF resources at household and community levels is knowledge of the WEF nexus. This section presents the general knowledge of WEF nexus by the households and communities as well as what the households and communities proposed as WEF nexus solutions.

During the focus group discussion communities were able to identify WEF nexus linkages. Generally, a good understanding of nexus but weak operationalisation, as well as linkage to climate change and sustainable development in the community. In particular, there was low awareness of resource use, emissions and climate change. Table 5.5 presents the identified

nexus knowledge of the community in the study area. Further indirect nexus with social economic outcomes such as food prices and environmental degradation were identified. For example, this was one of the observations by the community during an FGD. From the aforesaid, there is an opportunity to increasingly focus on dissemination and promoting sustainable development technologies in the community. The following is what one of the community members stated during the FGD session:

> *"The high cost of conventional energy sources such as electricity has forced us to increasingly rely on fuel wood from forests. This is increasing depletion and degradation of the scarce forestry resources which further leads to soil erosion"*

Table 5.5: WEF nexus knowledge of the community in the study area

Nexus linkage identified	**Practical areas identified in the nexus**	**Remarks by the community suggesting knowledge of the WEF nexus**
Water for food	Water is required to cook Water is required to pump water to irrigate crops Rainwater is a must to grow crops	You cannot cook without water When there is no rain, crops cannot grow
Energy for food	Energy is required to transport food from stores Energy is required to boil water Energy is required to transport fuel wood to cook	We use transport to get to stores to buy food and this transport uses fuel (diesel/petrol)
Energy for water	Energy is required to pump water	To irrigate the land, we use pumps which are driven by electricity
Water for Energy	Water is used to generate electricity (hydropower)	In the past, we used to get electricity from a mini hydro station upstream. The scheme no longer works because water levels went down

The knowledge of nexus is also correlated with how individuals perceive their importance. Generally, there was a higher regard for the importance of water in crops and horticulture (15.3% and 12.9% respectively) than in livestock at 3.2%. This could be related to low livestock activities among households relative to crop farming. The perception of the importance of energy in the WEF nexus increased in households with livestock and crop enterprises at 12.5% and 31% respectively. The perception of energy in horticulture was noted at 25%. It could be argued that the perception of the importance of knowledge of nexus is related to nexus practice and the technology used.

Informational campaigns and awareness creation on the WEF nexus is thus an urgent need if sustainability objectives are to be achieved at the household and community level. Most respondents (64.8%) didn't know whether water and energy are important in livestock production. However, high and low importance of water in livestock production was reported at 28.9% and 6.3% respectively. About 10% of the respondents perceived the high importance of energy in livestock, with the low importance of energy at 24.2. It was noted that 0.8% didn't respond to this section. A considerable proportion of the respondents (48.4%) perceived the low importance of energy in horticulture production, while 18.8% reported the high importance of energy in horticulture. About 32.8% of the respondents did not know whether energy is important in horticulture production or not.

A sizeable proportion of the respondents (43.8%) thought that water is very important for horticulture production, while 25% thought that water is not important in horticulture production and 31% could not form an opinion on the importance of water for horticulture production. The majority of respondents (60.2%) perceived low importance of energy in crop production. Only

14.8% reported the high importance of energy in crops and 25% did not know the importance of energy in crop production. The importance of water in crop production was reported as high at 46.9%, low at 29.7 and the remaining 23.4% did not know the importance of water in crop production. The results show that most of the community members do not see the link between energy and food production (crop and livestock production), hence they perceive energy as not important in the food sector.

5.5.2 Governance opportunities

Though access to information in agricultural production is one of the prerequisites and drivers for agricultural development, information sharing is a sensitive concept (Padre et al., 2003). Agricultural information dissemination plays a central role in the development of agriculture. The sources of information from this knowledge-intensive industry include scientific research and indigenous knowledge. Sustainable agriculture requires the dissemination of the right knowledge and information to farmers and other stakeholders at the right time, in a user-friendly and accessible way (Odongo, 2013). FAO (2009) indicates that increased transmission of knowledge and information is critical at every stage of the agricultural production chain, material inputs, and sustainable agricultural development. Agricultural knowledge and information are effectively generated, captured and disseminated through knowledge management systems with clearly defined mechanisms (UNDP, 2012).

Innovation platforms (IPs) not only increase the reach but also reduces transaction cost for new technologies as well as innovation. Membership to innovation platforms among the respondents was critically low with only 11% of the surveyed respondents being in any form of IP. However, all members in an IP had received some form of agricultural training such as field days suggesting that IPs could be very important in increasing access to technology and innovations. It was noted that only 3.1% of members in IP have access to extension services. This shows that those who belonged to IPs were more likely to be visited by extension agents than those who did not. This is especially critical in light of low extension coverage in the area.

5.5.3 Suggested WEF nexus governance solutions

The community members proposed the following WEF nexus solutions during the FGDs:

- Strengthening the integration of the WEF sectors
- Improve coordination mechanism among the WEF sectors and actors
- Improve access to information, education and public awareness;
- Enhance transparency and accountability among the WEF institutions and actors;
- Improve access to credit
- Deepening the Land reform in particular the use and control of rights
- Improve access to education, extension, and advisory services; and
- Enhance the use of innovation platforms for synergies, wider reach and access.

Availability and Consistency of supply which are closely correlated at 69% and 37% respectively were the most dimension suggested by the community as areas that need urgent attention on water security governance (Table 5.6). The cost was mentioned at 26%. The low concern on cost in water governance is due to the free water policy in most communities. However, the community incurred costs in accessing water from private suppliers due to frequent/long cut-offs.

Table 5.6: Suggestions for improving water security

Suggestions		Responses	
		N	Percent
Suggestions to improve water security[a]	Availability dimension	71	45.5
	Cost dimension	27	17.3
	Consistency dimension of water security	38	24.4
	Non-specific Suggestions to improve Governance water governance	20	12.8
Total		156	100.0

As for energy security, the cost dimension (40%) was considered the main concern, while the availability of alternatives (33%) and consistency in supply (27%) emerged as issues of major concern in the governance of energy security among the respondents (Table 5.7).

Table 5.7: Suggestions for improving energy security

Suggestions		Responses	
		N	Percent
Suggestions to improve energy security[a]	Availability dimension	62	32.8
	Cost dimension	76	40.2
	Supply consistency	51	27.0
Total		189	100.0

The results in Table 5.8 show that the cost of food (64%) was the dimension of food security that the respondents wished to be addressed. Access and availability concerns stood at 27% and 25%, respectively.

Table 5.8: Suggestions for improving food security

Suggestions		Responses	
		N	Percent
Suggestions to improve food security[a]	Availability dimension	10	21.3
	Cost dimension	26	55.3
	Access to food security	11	23.4
Total		47	100.0

5.6 Discussion, conclusions and recommendations

5.6.1 Discussions

Bizikova (2013) conducted a comparative review of case studies to explore integrating the identified nexus linkages into policy design and implementation. The review focused on nexus-related local and regional challenges using various research approaches to analyse WEF linkages and the activities integrating them into the public policy design.

The Strategic Plan 2020-2025 of the DMRE has been included in its integrated resource plan. The plan also emphasized that cooperation between the DMRE, DWS and Department of Forestry, Fisheries and the Environment (DFFE) towards implementing one environmental system will be encouraged. However, at the local level, its intent is yet to be felt as a segmented/silo approach to dissemination is apparently missing on potential synergies amidst human and financial resource constraints in the WEF agenda. This reflected the segmented

and silo approach by various stakeholders on WEF at the household level. Accordingly, there is low awareness, technical know-how, enabling environment on financing, and incentivisation of smart WEF practices at the household level.

Communication for development involves the planned use of strategies and processes in achieving development and behaviour change (Srampickal, 2006). It is concerned with re-engineering diffusion to a process of innovation. Its three basic components are advocacy, social mobilisation and behavioural change (or behavioural development). Advocacy educates and motivates community leadership to create a supportive environment to achieve programme objectives and related development goals. The advocacy component is focused on changing policies, resource allocation, public dialogue and conversation on important issues. Social mobilization encourages and supports the participation of institutions, community networks, and social/civic and religious groups to raise the need for or sustain progress towards a development objective by strengthening participation in activities at the grass-roots level. Communication channels are critical in the pursuit of this objective. Enhancing their effectiveness regarding the WEF agenda in the study area will go a long way in adopting smart WEF innovations and practices. This is particularly critical due to existing low access to extension services as well as the low presence of innovation platforms in the area. Furthermore, the use of innovation platforms in promoting and disseminating sustainable WEF technologies and practices as well as to spur innovation and learning in the community could significantly contribute to increased adoption.

There is a need for increased policy coherence, effective operationalisation and implementation of policy through appropriate governance instruments and institutions and a decrease in the impact of the most influential stakeholders/agents and their vested interests. Hoff and Ulrich (2017) further argue that critical for the materialisation of these benefits is the existence of political will. Financing was an important enabler and a barrier to adopting smart WEF innovations and practices. However, low access to finance/credit coupled with high unemployment undermines the adoption of smart technologies. This along with other barriers, such as unfavourable government policy and regulatory framework as well as lock-ins, lack of technical know-how and inadequate access to information, are key variables in the governance and institutional arrangement. Engaging across sectors and levels, both within, across and outside governmental agencies and institutions as well as coordination of this collaborative effort could address the barriers and institutional bottlenecks that disincentivise smart WEF implementation at a local level.

WEF nexus and management is a cross-cutting with chain impacts across the socioeconomic spectrum. Its implementation requires attention to barriers and creating an enabling environment for households to adopt. In agreement with Koulouri and Mouraviev (2019), collective governance as an arrangement seems to be necessary to bring all actors across the regulatory, natural resource management, change management, communication, financing and service providers both state and non-state actors to design a plan of action that addresses the constraints in its implementation. This could in turn create a win-win situation and synergies among the actors and the society at large. Innovation platforms could play a critical role in this direction, increase research extension linkages, increase extension coverage, and serve as an arena to identify felt and expressed as well as unexpressed WEF needs in the community. It would also serve as a platform for the promotion of WEF smart technologies and feedback on the design and policy intervention.

5.6.2 Conclusions

The study aimed to contribute to policy and decision-making processes, and support the adoption of nexus innovations and practices and enhance the sustainability and resource security of each component system in the Nzhelele and Luvuvhu river catchment areas of the VDM in the Limpopo Province of South Africa. The barriers and enablers to adoption identified here as well as policy and governance gaps identified will go along in pursuit of the nexus

agenda. The interrelation of the nexus resources can be visualised from their importance, use and chain impact. To a greater extent, the communities are able to link the WEF resources and the chain impact. Several barriers at policy and informational levels as the socio-economic challenges such as poverty undermine the WEF nexus implementation. This will require collaborative institutional and governance approaches as the challenges are cross-cutting. In particular, knowledge, informational and financing barriers need to be accorded greater attention. The use of innovation platforms may greatly increase synergy. This is also to streamline the governance structures, and institutional arrangements in the planning implementation, monitoring and evaluation of WEF nexus problems and objectives.

The analysis of the degree of support of the legislation, policies, and strategies for the WEF nexus approach shows that the Constitution provides solid support for the WEF nexus approach. However, there is a complex collaboration between interconnected sectors, diverse sectoral institutional frameworks and insufficient governance frameworks that must be overcome to improve the WEF nexus approach at the sectoral level. Another challenge is a lack of incentive to collaborate with multiple stakeholders from many disciplines and government levels. Some of the sectoral policies and strategies do explicitly support the WEF nexus approach in their design and implementation. These are challenges which must be overcome in order to achieve the best out of the nexus approach.

The study has identified two main areas which must be addressed. The first area is the apparent limited support offered by national legislation, policies, and strategies for the WEF nexus approach. There is more to be done to integrate WEF nexus principles in national and sectoral legislation, policies and strategies. The second area is that communities have limited knowledge and understanding of the nexus nature of the WEF resources they manage and utilise. Successful implementation of the WEF nexus approach at local and household levels depends on, among other things, the communities' understanding of the extricate connectivity and linkages of the WEF resources, and hence their understanding of the synergies and trade-offs that exist as they manage and use the resources. The results of the study show that there is more to be done to enhance communities' knowledge and understanding of these basic linkages among the WEF resources. In order to improve synergetic solutions between the systems in which resources and activities are arranged to provide final services for the community, communities need to be aware of the nexus perspective. Given the increasing understanding of the inter-connectedness between the systems, conventional perspectives dealing with the systems separately would not be seen as effective even from each system itself and the sustainability aspect of the community.

5.6.3 Recommendations

The following recommendations were made based on the results of the study:

1) Integrate WEF nexus in national and sectoral legislation, policies and strategies to enhance the support of these to the implementation of the WEF nexus approach in communities;
2) Support multi-stakeholder forums to operationalise a sector-wide approach to addressing the barriers and creating an enabling environment for WEF coordination and adoption, especially with respect to financing, addressing policy bottlenecks and information dissemination and smart WEF technology diffusion;
3) Strengthen multi-level and cross-level WEF coordination mechanisms;
4) Review of institutional frameworks to align itself with the WEF agenda and cross-cutting issues such as financing;
5) Strengthening WEF nexus policies, strategies and regulations, implementation, monitoring and evaluation;
6) Improve the coordination of multilevel and cross-level actors;
7) Enhance the effectiveness of communication channels (electronic, digital and print as well as social media) to enhance their impact on knowledge dissemination and address the weakness in extension and advisory services;

8) Explore innovation platforms as vehicles for dissemination, innovation, and extension and advisory service delivery;
9) Conduct public information and awareness campaigns on sustainable WEF innovations and practices; and
10) Engage in policy advocacy on existing WEF policies, strategies and regulations and their enforcement.

6 CHAPTER 6: POLICY, GOVERNANCE AND INSTITUTIONAL FRAMEWORKS

6.1 Stakeholder consultations

The frameworks were developed based on the outcomes of a desk review of practical frameworks used in the application and assessment of the governance of natural resources such as water, key informant interviews (KIIs), and Focus Group Discussions (FGDs). Although six villages were initially purposed for the study, one village could not be accessed due to the unwillingness of community leaders to participate in the study. This unwillingness was triggered by acute water scarcity and the insufficient municipal water supply they were facing. Questionnaires were administered in Siloam, Khalavha, Phadzima, Sambandou and Malavuwe villages between August-September 2022. This was supplemented with FGDs and KIIs. In addition to households, KIIs and FGDs were undertaken within and outside the study area. The KIIs were carried out with the Department of Agriculture and Rural Development, Water and Sanitation, Forestry, Fisheries and Environment, Municipal managers as well as the National Environment Management Authority (NEMA), Northern region. To collaborate information on communication in WEF, KIIs were undertaken from media houses including Phalaphala FM, Univen FM and SAB, Thohoyandou. Figure 6.1 key informant interview in progress.

Focus group discussions involved 7-13 members at community (common) public centres. In total 6 FGDs were held, one for each village. The themes were based on a checklist and facilitated in Tshivenda language using a trained facilitator. Figures 6.1 and 6.2 show focus group discussions in progress.

Figure 6.1: Key informant interview with the Department of Agriculture, in Thohoyandou (Source: Research Team)

Figure 6.2: Focus group discussion in progress through a facilitator (Source: Research Team)

6.2 Overview of the policy and governance frameworks

Water, energy, and food are inextricably linked in a nexus, and actions in one sector influence the others (Rasul, 2016). Production of food requires water and energy; water extraction, treatment, and redistribution require energy; and energy production requires water (Bazilian et al., 2011; Hussey and Pittock, 2012). Food production and freshwater services depend on water, land, and other natural resources, in other words, a range of ecosystem services (FAO, 2014; Rasul, 2014; Boelee et al., 2011). Choices on food and agricultural practices influence water and energy demand. Similarly, the demand for water, energy, and land is influenced by different policies, for example, those relating to agriculture, energy, land-use, food, fiscal, credit, prices, and subsidies (Rasul and Sharma, 2015). While these relationships are dynamic, policies and governance systems are generally narrowly sectoral, with a disconnect between those for food, water, and energy (Hussey and Pittock, 2012; Rasul, 2016). By ignoring the underlying interdependence of the three sectors, policies and governance systems sometimes have the unintended consequence of shifting a crisis from one sector to another (Tomain, 2011); and policies and actions taken in isolation, without considering their

impact on other sectors, can aggravate resource constraints (Hermann et al., 2012; Scott et al., 2011).

While policy and governance systems influence the implementation of the WEF nexus approach, it is observed that both policy and governance also benefit from implementing the nexus approach (Koulouri and Mouraviev, 2019). Often decisions on how to intervene are made without cross-sectoral coordination, targeting sector-specific optima and, thereby, resulting in risks and uncertainties across sectors and scales (FAO, 2014). A cross-sectoral nexus approach provides an opportunity to engage with a broad range of stakeholders from local to national governments, basin organisations, development banks and agencies, international and regional organisations, research institutes and universities, NGOs, civil society and the private sector (FAO, 2014). The Nexus approach considers the different dimensions of water, energy and food equally and recognizes the interdependencies of different resource uses to develop sustainably. Policy instruments to facilitate or constrain an action towards achieving a desirable outcome – in this case, one of the WEF securities – need to be evaluated not only for their impact on the provision of the intended collective good but also for how far they impact the provision of other goods of interest (Srigiri and Dombrowsky, 2021).

From a policy and governance perspective, there are multiple advantages to adopting the nexus approach in policy design and implementation for the WEF sectors (Hoff and Ulrich, 2017). These include increased policy coherence, effective operationalisation and implementation of policy through appropriate governance instruments and institutions and a decrease in the impact of the most influential stakeholders/agents and their vested interests. Hoff and Ulrich (2017) further argue that critical for the materialisation of these benefits is the existence of political will – locally, regionally and globally – to engage across sectors and levels, both within, across and outside governmental agencies and institutions and to coordinate this collaborative effort.

The core premise of the WEF nexus approach is that the policy objectives in one sector (water, energy or food) can interact with those in other sectors because they are either preconditions for the realisation of another sector's objectives or one sector (system) imposes conditions or constraints on what can be achieved in the other sectors (Weitz et al., 2014). On the other hand, the governance context, along with the formal and informal rules that dictate how decisions affecting the allocation of resources are made, determine the outcomes of a nexus approach (Weitz et al., 2016). Providing access to improved water sources, sanitation facilities and electrification is viewed by most citizens as a barometer of good governance and is reflected in both the MDGs and SDGs (Simpson and Jewitt, 2019). Benson et al. (2017) argue that effective governance for the nexus occurs when the integration of resource sectors is actively pursued, such that synergies between water availability, energy generation and food production are enhanced, while trade-offs are managed, and potential conflicts are averted.

It is argued that, while the WEF nexus has especially been advocated to address conflicts among the sectors, policy and governance questions related to the WEF nexus have not received much attention, particularly the institutions and politics governing the WEF sectors (Foran, 2015; Scott, 2017). Regarding the WEF nexus practices, it is reported that policies are too often incoherent, fragmented, and inefficient (Sadoff, 2022).

6.3 The WEF nexus Governance framework

The proposed governance framework is a combination of governance actors, governance functions, governance attributes, and governance outcomes, producing an easy-to-understand, easy-to-use operational framework on which practitioners can define their interventions (Fig. 6.3)

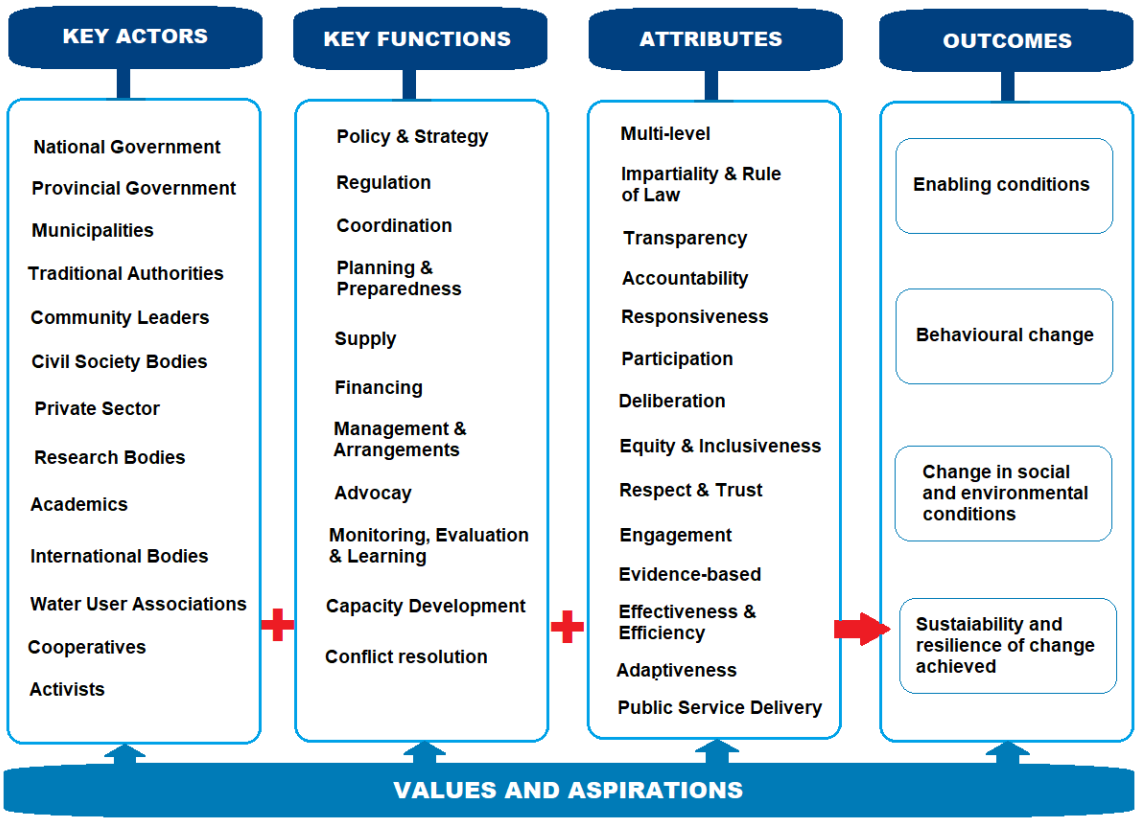


Figure 6.3: Proposed governance framework, as a combination of key actors, functions, attributes and outcomes
(Adapted from Jiménez et al., 2020)

6.3.1 Key governance actors

The proposed framework consists of multi-level governance (MLG) which is characterised by the participation of various actors and different levels. Multiple actors across different institutional levels play a role in water-energy-food governance. The capacity and interest of actors involved in the WEF sectors – including line ministries, regulatory agencies, municipalities, citizens, civil society organisations and private enterprises at all levels shape governance structures and the management of WEF-related resources. Benefits from the management of WEF-related resources are likely to be more equitable, sustainable and effective if capacities are high amongst all actors, if their interests are aligned and negotiated transparently and if their resources and negotiating powers are on an equal footing (SDC, 2018).

Governance of WEF resources involves processes, mechanisms, instruments and platforms that promote and ensure multilevel, multi-sectoral, and multi-stakeholder cooperation among all actors (Jiménez et al., 2020). In this framework, the key actors include relevant ministries and departments of national, provincial and local governments (municipalities), traditional authorities, community leaders, civil society bodies, academia, research bodies, water user associations, cooperatives, activists, external support agencies (international bodies), and the private sector.

6.3.2 Key governance functions

The key governance functions are the key processes performed, in various forms and to varying extents and quality, for the organised development and management of WEF resources and services. They include the main activities that the responsible organisations should undertake or facilitate, in cooperation with other stakeholders, to develop the sectors. The functions include formulation of policy and strategies.

Policy and Strategy – Policymaking is a crucial governance function that involves the development, formulation, and implementation of laws, policies, and strategies. This function comprises the set of norms, principles and priorities to achieve desired outcomes, as well as the set of rules, procedures, programs and/or mechanisms needed to achieve such ends. It provides the framework for links and interdependencies between the WEF sectors, harnessing synergies while managing potential conflicts (Jiménez et al., 2020).

Regulation – This function covers formal legal mechanisms, enforcement processes and other rules to ensure that stakeholders fulfil their mandates and that standards, obligations and performance are maintained, as well as to ensure that the interests of each stakeholder are respected (Jiménez et al., 2020). The regulatory authorities set standards and establish rights, accompanied by ensuring effective accountability mechanisms to determine clear roles and responsibilities, monitoring mechanisms and penalties across sectors. Accountability mechanisms include organisational responsibilities for the core regulatory processes and the links between regulators and those they regulate. The regulation also includes the capacity to enforce agreed standards and impose sanctions for noncompliance.

Coordination – This function comprises the processes, mechanisms, instruments and platforms that promote and ensure multilevel, multi-sectorial, and multi-stakeholder cooperation among all actors – relevant ministries and departments of national, provincial and local governments, civil society, academia, external support agencies and the private sector. It involves facilitating information sharing, dialogue and collaborative decision-making, linked to policy-making and planning. Coordination forms an important part of most governance functions, and specific coordination processes and mechanisms might be needed under particular circumstances (e.g. emergency or disaster response).

Planning and Preparedness – Planning is the process of data collection and analysis, formulation of actionable plans and estimation of costs (Jiménez et al., 2020). Planning produces time-bound roadmaps with estimations of human and financial resources. Plans not only focus on expanding or increasing the level of service or securing adequate and good quality WEF resources for different purposes, but also on sustaining service levels while developing water, energy, and food resources sustainably, by ensuring continued investment in asset maintenance and adequate management regimes. Preparedness refers to the arrangements, capacities and knowledge developed by governments, response organisations, external agencies, communities and individuals to anticipate and plan, to be able to mitigate and respond effectively to the impact of potential or current shocks and stresses, including those related to climate change (UNISDR, 2009).

Supply – This function relates to processes of supplying goods and services to households and communities for the use and management of WEF resources. For example, municipalities and Eskom supply electricity to consumers, while private sector entities supply agricultural services and inputs to farmers, and products for treatment of water supplies.

Financing – This function relates to the ability to raise funds from different funding sources to cover all the elements of water services or water resources management throughout the entire lifecycle. This function also includes forecasting, i.e. the ability to project the costs under different scenarios – and budgeting, i.e. the ability to plan expenditures within a certain time horizon.

Management Arrangements – This function refers to the combination of organisational, managerial and institutional arrangements at national and sub-national levels, that support the functioning of the management entities. In service provision, it entails the definition of the service delivery model – who owns, who invests, who develops and who operates the infrastructure, who supervises and provides technical support, and the relationship among all these actors, and with the users.

Advocacy – This function relates to the processes of promoting and advocating good governance, transparency, accountability and integrity. This is a function often performed by civil society bodies and activists. This function is based on exploring and advancing the key governance principles of democracy, transparency, accountability, responsiveness, and combining these with upholding the rule of law and respecting human and civil rights.

Monitoring, Evaluation and Learning – This function refers to ongoing, systematic processes of collecting, analysing, evaluating, and using data to track performance and inform planning and decision-making. Evaluation is an exercise to systematically and objectively assess the progress and achievement of an outcome, which may include an assessment of an activity, project, programme, strategy, policy, topic, theme, sector, operational area or institution's performance (UNDP, 2009a). Evaluation helps in determining the relevance, impact, e effectiveness, efficiency and sustainability of the intervention (UNDP, 2009a). Learning includes formal and informal processes, whereby stakeholders exchange good practices and information and use the newly acquired knowledge in managerial decisions to adapt and improve policies and programmes (Jiménez et al., 2020).

Capacity Development – This function refers to the processes by which organisations, society and individuals systematically stimulate, develop, strengthen and maintain their capabilities over time to set and develop their goals and objectives to be able to manage WEF resources and services sustainably (UNISDR, 2009, UNDP, 2009b). This can be through knowledge development, awareness building, training and skills development, and improving systems and processes.

Conflict Resolution – This function refers to the processes by which community leaders, traditional authorities and individuals facilitate open communication and discussion through mediums of debate, dissent, mediation and negotiation to create a common ground of collective action. The function of conflict resolution mechanism is one of the key instruments in the WEF resources conflict management and in improving cooperation processes, by building trust among users of shared resources.

6.3.3 Governance attributes

As indicated in Figure 6.3 above, the governance framework is based on 14 attributes. The attributes are related to how governance functions can be performed. The attributes that establish a baseline for good governance include promoting legitimacy and voice through participation, consensus, and informed decisions; the performance of institutions and processes through responsiveness, effectiveness, and efficiency; promoting accountability and transparency; ensuring fairness by implementing equity, rule of law, and conflict management (UNESCAP, 2009).

Multilevel governance – Multilevel governance implies that there are decision-making centres or governing authorities at different levels (vertical) or layers (horizontal, i.e. arrangements that may not necessarily stand in a hierarchical order but have a certain level of independence and interdependence between institutions within the same level of governance (Lebel et al., 2006; Cole, 2011). Such governance systems can be of different forms, and the terminologies are sometimes used interchangeably. Within this, nested and polycentric governance are common descriptors used in academic literature. Nested systems are those where key governance functions are organised into multiple reinforcing layers of governance but are not necessarily independent of each other (Ostrom, 2010), i.e. with functional linkages between levels or layers. Polycentric systems are those where decision centres are present in different layers and are independent of each other, with a certain degree of power and financial autonomy (which may not be the case in a hierarchical structure), such as in municipalities (Lebel et al., 2006; Ostrom, 2010).

Impartiality and Rule of law – Impartiality and Rule of law refer to having legal frameworks and mechanisms that are designed and enforced impartially, in a fair and non-discriminatory manner, reflective of the human rights-based approach (Jiménez et al., 2020). Rule of law refers to having legal frameworks and mechanisms that are designed and enforced impartially, in a fair and non-discriminatory manner, reflective of the human rights-based approach. The rule of law is fundamental to peace and security and political stability; to achieve economic and social progress and development, and to protect people's rights and fundamental freedoms. 9 It is foundational to people's access to public services, curbing corruption, restraining the abuse of power, and establishing the social contract between people and the state. Rule of law and development are strongly interlinked and a strengthened rule of law-based society should be considered as an outcome of the 2030 Agenda and SDGs. The UN 10 refers to the 'Rule of law' as a core principle of governance, where all (including institutions, entities, public, private, and the state) are accountable to laws established that are consistent with international human rights norms and standards. In addition, the rule of law is required to ensure adherence to the principles of supremacy of law; equality before the law; accountability to the law; fairness in the application of the law; separation of powers; participation in decision-making; legal certainty; avoidance of arbitrariness, and procedural and legal transparency (Jiménez et al., 2020).

Transparency – Transparency refers to "openness and public access to information so that citizens can understand the decision-making processes that affect them, and are knowledgeable about the standards to expect from public officials" (UNDP-SIWI, 2011). Transparency requires governments, companies, organisations and individuals to facilitate all means for citizens to understand the decisions that may affect them; and it requires the information to be usable through open data, that is accurate, available, complete, conformant, consistent, credible, processable, relevant and timely (Dekkers et al., 2014).

Accountability – Accountability refers to the principle whereby elected officials and those that have a responsibility in water services or water resources management account for their actions and answer to those they serve (UNDP-SIWI, 2015; Jiménez et al., 2018). The Human Rights framework identifies three essential principles for building accountability (a) responsibility: defining roles and responsibilities in service delivery and enabling coordination between different stakeholders, (b) answerability: by providing reasoned justifications and explanations for their actions and decisions to those they affect, (c) enforceability: by providing monitoring, supporting and enforcing compliance for the use of corrective and remedial action where necessary, such as sanctions for corrupt behaviour (Jiménez et al., 2018).

Responsiveness – Good governance needs institutions and processes to attempt to serve all stakeholders within a reasonable time. responsiveness and accountability as the most salient features of governance for effective sustainable development policies and delivery of essential public services. A good governance system needs to respond to the real needs of the people and be accountable for their decisions and actions to them. Responsiveness is linked to trust in government, which in turn, is essential for encouraging cooperation and compliance with laws and regulations. There is therefore a reciprocal relationship between public trust in governments and their associated organizations, and responsive governance (United Nations, 2015). According to Accountability Initiative 11 , responsive governance operates on three levels.

a) As a framework: it aims to make existing accountability mechanisms stronger and facilitate their inclusion as a key feature in new policies.
b) As a call to action: Responsive governance rethinks the dialogue and sharing of knowledge in public policy. It seeks to reconfigure the interaction between government

9 https://www.un.org/ruleoflaw/what-is-the-rule-of-law/
10 Ibid
11 https://accountabilityindia.in/about-us/#who-we-are

service providers and the public at the local, state and country-levels to facilitate conditions for transparent governance.

c) As an ideal: Responsive governance is also the guiding beacon for all efforts towards efficient and accountable public service delivery, within the government and those by civil society.

Participation – Participation, in the concept of good governance here is an opportunity for everyone to voice their opinions through institutions or representations. In addition, everyone, without exception, has the right to freedom of association and expression. Hence, participation implies the meaningful and active involvement of a broad spectrum of stakeholders, including vulnerable or marginalised groups in decision-making processes. Participation can coordinate many different attributes and goals, reduce the costs of conflict, and improve the efficiency of resource use (Rydin and Pennington, 2000).

The human rights framework to water and sanitation defines six procedural elements as crucial for achieving free, active, and meaningful participation: involving people in the design of the participatory procedures; creating access to participatory spaces; enabling environment of free and safe participation; access to reliable and complete information in a timely manner, which is easy to understand and comes at no cost; providing support to enable effective contributions from the stakeholders; and having the opportunities to influence decisions taken in the sector along with the right to know how their inputs were considered, what decisions were made and implemented, and on what grounds (United Nations General Assembly, 2014). However, these procedural aspects also need to be adapted to the context, and the level of capacity and resources, and the attitudes towards the participatory process are also essential for its success (UNDP, 2009a).

Deliberation – Deliberation features mechanisms that facilitate open communication and discussion through mediums of debate, dissent, mediation and negotiation to create a common ground of collective action (Jiménez et al., 2020). A deliberative process is required to establish a joint vision and consensual understanding of a shared resource (quantity and quality). This governance attribute could also be important in the context of conflict management and cooperation between private and public sectors and utilities involved in water and energy services provision; or on issues arising between communities and decision-makers (Jiménez et al., 2020).

Equity and Inclusiveness – Inclusiveness is recognising the rights of individuals and groups across different categories, needs and vulnerabilities, and without any kind of discrimination based on race, colour, age, gender, religious affiliation, ethnicity, language, disability, economic background or any other conditions of origin (Jiménez et al., 2020). It also concerns taking into consideration these diverse social, economic, and cultural aspects, along with taking special account of the vulnerable groups, minorities and indigenous people when performing different governance functions, contributing to balancing differences in power (Jiménez et al., 2014). This attribute is closely related to equity, for example by designing and implementing pro-poor financing strategies, equitable distribution of water; or mainstreaming gender in planning, policy, financing, and monitoring of water services and resources.

Respect and Trust – Respect and trust are fundamental attributes of good governance. A good governance system is built on respect and trust of the cultural and social values of communities. Lack of respect for cultural and social values associated with the WEF resources in communities poses the greatest obstacle to a sense of ownership by the communities and sustainable interventions. Imposing both technical and management solutions that are not culturally and socially suited and acceptable humpers successful implementation of the WEF nexus practices. A long-term commitment to communities by national, provincial and local institutions builds relationships of trust and understanding, which are especially valued by communities as users of the WEF resources (Jiménez et al., 2014). Rest and trust in the WEF

governance relate to the contribution of governance to building public confidence and ensuring inclusiveness of stakeholders through democratic legitimacy and fairness for society at large (OECD, 2015)

Engagement – Engaged governance is a governance strategy that links citizens more directly into the decision-making process of the State in order to enable them to influence the public policies and programmes in a manner that impacts more positively on their social and economic lives.12

Evidence-based – Evidence-based decision-making around WEF resources seeks to identify and leverage reliable technical and scientific, empirical and contextual evidence for decision-making (Jiménez et al., 2020). This includes collection and dissemination of accurate and current knowledge and information related to natural and social sciences; drawing upon inputs from specialists and subject matter experts and using advanced information systems; learning from past failures and successes; and including local knowledge and cultural values. It is important to ensure that the information reaches the appropriate decision-makers and technical staff involved in WEF-related decision-making in a timely manner (Head, 2010; Pahl-Wostl, 2017; Pezij et al., 2019).

Effectiveness and Efficiency – Every decision-making process and its institutions must be able to produce decisions that meet every community's needs. Community resources must also be utilised optimally by the government. Efficiency in process management means that processes and institutions produce results that meet the needs of society while making the best use of resources at their disposal (UNESCAP, 2009). This includes workflows, specific activities, and steps that must be taken with the objective of providing a clear idea of how the processes serve to transform the inputs into an effective and sustainable output. The effectiveness of the governance of the WEF resources relates to the contribution of governance to define clear sustainable WEF-related policy goals and targets at different levels of government, to implement those policy goals, and to meet expected objectives or targets (OECD, 2015). On the other hand, the efficiency of the WEF governance relates to the contribution of governance to maximize the benefits of sustainable WEF management and welfare at the least cost to society (OECD, 2015).

Adaptiveness – Adaptiveness in governance means the ability to self-organise, learn, respond, cope and use adaptive management strategies in situations of uncertainties, risk and nonlinearities. Self-organising is a common feature of adaptiveness and it refers to the ability of a system to maintain and re-create its identity by safeguarding itself from the impacts of other systems (Holling, 2001; Lebel et al., 2006). It is important to ensure that during situations of uncertainties and risks, the system is capable of self-organising through formal and informal arrangements and that there are mechanisms and platforms to facilitate collective learning, knowledge sharing and innovative approaches for the implementation of the existing governance functions; for example, establishing capacity development mechanisms that promote awareness raising campaigns, support community or stakeholder networks and mobilisation.

Public Service Delivery – In the realm of delivering state services to the public, good governance reforms advance human rights when they improve the state's capacity to fulfil its responsibility to provide public goods which are essential for the protection of a number of human rights, such as the right to clean water, education, health, and food 13. Reform initiatives may include mechanisms of accountability and transparency, culturally sensitive

12 http://www.asset-scienceinsociety.eu/pages/engaged-governance

13 https://www.ohchr.org/en/good-governance/about-good-governance#:~:text=In%20summary%2C%20good%20governance%20relates,economic%2C%20political%20and%20social%20rights.

policy tools to ensure that services are accessible and acceptable to all, and paths for public participation in decision-making.

6.3.4 Governance outcomes

The performance of the governance system is evaluated on the basis of criteria of outcomes as well as of processes (Srigiri and Dombrowsky, 2021). Hence, the performance of core governance functions can only be understood when linked to how these functions are conducted (attributes), leading to the desired outcomes of the governance process (Jiménez et al., 2020). Outcomes typically include the effectiveness and efficiency of coordination mechanisms in achieving shared goals. In the context of WEF nexus, the outcomes also include reduced trade-offs and increased synergies among contextualised goals and strategies. Processes in achieving the shared goals should also be part of the evaluative criteria, which include accountability, due representation of interests of all actors and actor groups concerned, and opportunities for social learning provided by the governance processes. A relatively important process criterion for assessment is the adaptability of the governance system to deal with external shocks such as climate change-induced extremities or economic shocks.

In this framework, the Orders of Outcomes framework proposed by Olsen et al. (1999) and Olsen (2003) for the governance of source-to-sea systems are adapted. They propose measurable outcomes disaggregated into four 'orders' that lead to the ultimate long-term goal of sustainable forms of development (Granit et al., 2017), as shown in Table 6.1.

Table 6.1: Four orders of outcomes in a governance system

Order of Outcomes	Description
First	Creation of the enabling conditions for a governance initiative.
Second	Behaviour changes of resource users and key institutions.
Third	Achievement of desired changes in societal and environmental conditions.
Fourth	A resilient social-ecological system where desired conditions are sustained.

(Adapted from Granit et al., 2017)

The First Order of outcomes relates to the setting in place of the enabling conditions necessary to perform all governance functions, including agreement on goals and objectives in combination with the necessary commitment, buy-in and capacity among key government agencies and stakeholders (Granit et al., 2017). They are context-based, thus changing from programme to programme and from place to place.

The Second Order of outcomes come during implementation and refers to the change in behaviour among user groups and institutions in performing the governance functions (Jiménez et al., 2020). They include (1) changes in how institutions and groups relate to one another (e.g. enhanced cooperation, improved trust); (2) changes in how user groups relate to the resource (e.g. responsible water and energy consumption, compliance with agreed regulations for water and energy discharges); (3) evidence of implementation of the agreed vision, goals and objectives (e.g. financing is made available to support implementation, and monitoring and evaluation takes place) (Olsen, 2003).

The Third Order of outcomes are defined by the goals and objectives set as part of the first order outcomes. While Third Order outcomes are context-based, outlined as part of a policy and strategy process, they generally aim for nationally and internationally agreed outcomes (e.g. Sustainable Development Goals), such as improved status of the WEF resource and the related ecosystems, increased and equitable access to services and strengthened resilience (Jiménez et al., 2020). The Fourth Order of outcomes are achieved when the desired social

and ecological conditions remain over time, and the system is able to adapt and absorb changes and stresses and "development meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

6.3.5 Foundation of the governance framework

The combination of functions and attributes to achieve certain outcomes is influenced by the existing *values and aspirations* of all stakeholders taking part in governance processes, as well as by the quantity of available resources that are allocated for this purpose (Jiménez et al., 2020). The values and aspirations of all stakeholders form the foundation upon which a good governance framework is founded. Agreed values tend to be formulated as "principles" in policy and strategy documents. It is important to consider customary practices, such as existing (recognised or not) local governance systems of water commons (e.g. traditional management of irrigation schemes, indigenous ecological governance models). The recognition and integration of these practices can be essential for achieving the intended outcomes of governance. Cultural beliefs and social norms related to water, land, and other natural resources are essential elements to be considered (Jiménez et al., 2020). Jiménez et al. (2020) argue that the values and aspirations, and resulting behaviours of individuals and organisations, linked to social norms, are additional components of the governance puzzle, which cut across the whole process, as depicted in the governance framework.

6.3.6 Applying the governance framework

There are various methods of applying WEF nexus governance to assess the performance of a governance system. The two methods covered in this report are the scores rating method and the social network analysis (SNA) method.

Scores rating:

The approach proposed by Alkharaz (2016) can be used to apply the framework for assessing a governance system. As mentioned above, the governance framework is based on 14 attributes. In this research, the attributes can be used to assess gaps that may exist in the governance system. An eleven-point system is used by which stakeholders are asked to give each attribute a score from 0-10. The value 0 means the attribute in question is not available or is applied in a very poor manner, whereas the value 10 means the variable is in agreement with the situation on the ground, and the attribute in question is available or applied in a very strong manner. Table 6.2 shows all scores and what each number indicates.

Table 6.2: Scores rating for governance attributes

Value	Rating
0	Worst
1	Very poor
2	Poor
3	Significantly below average
4	Below average
5	Average
6	Above average
7	Significantly above average
8	Good
9	Very good
10	Best

(Source: Alkharaz, 2016)

The value '5' is taken as a threshold in this analysis to identify governance gaps. An attribute is considered satisfied if it receives an average score of ≥5 and unsatisfied if it receives an average score below 5. The value '5' is chosen as a threshold because it represents the average application of an attribute on the ground. In this approach, each attribute is analysed

as an independent variable, hence, the value '5' is used in all attributes instead of determining different values for different attributes in order to eliminate correlation among the attributes (Alkharaz, 2016). The results can be presented in bar charts.

Social network analysis (SNA):
Network theory and analysis are increasingly being used to disentangle the complex interdependencies in polycentric systems, such as a governance system (Srigiri and Dombrowsky, 2021). SNA is a tool to understand the characteristics or structure of a network by identifying the actors involved in a network and their relationships, similar to actors in a governance system. This approach helps to understand how social relationships shape governance processes and provide opportunities and constraints for addressing complex and interconnected sustainability challenges (Stein et al., 2018). The centrality of different actors and actor groups is determined and influential actors with a bridging position are identified. Whether the understanding could be extended to the functionality of the networks is a question that is not fully explored in current studies (Lubell, 2013). Relational data generated from the network survey can be transferred into adjacency matrices representing various issue networks (Mollinga et al., 2007).

SNA relies on primary data collected from actors who are participants in selected action situations through a structured network survey questionnaire which focuses on the positional, relational and structural attributes of the network embeddedness. Alternatively, a "net map" is a method to determine the network in a participatory approach (Schiffer and Hauck, 2010).

Going beyond the quantitative SNA, semi-structured interviews with actors participating in action situations are useful to understand the considerations behind the decisions of actors as well as the structure of the action situation. Further, focus groups with groups of actors within an action situation are a useful technique to gather data on group dynamics and elicit particular kinds of historical or recent data, which are often found to be more reliable if they emerge out of a discussion among actors with similar interests.

6.4 Policy framework for managing the WEF nexus resources

The nexus approach requires a major shift in the decision-making process towards taking a holistic view and developing institutional mechanisms to coordinate the actions of diverse actors and strengthen complementarities and synergies among the three sectors (Rasul, 2016). The proposed policy framework is adapted from the frameworks proposed by Rasul (2016), Rasul and Sharma (2015) and Mabhaudhi et al. (2019). The framework is based on integrating policies and strategies in the three WEF sectors and supporting the move from a sectoral to a holistic approach.

6.4.1 Pillars of the policy framework

The key pillars of the WEF nexus policy framework are harmonizing public policies, aligning cross-sectoral strategies, converging cross-sectoral incentive structures, strengthening regulation, and facilitation of nexus-smart investment and technologies as illustrated in Figure 6.4. According to Mabhaudhi et al. (2019), the transformation of rural livelihoods and the sustainability of adaptation strategies is underpinned by the understanding of the role of the WEF nexus in framing effective policies and institutions.

Harmonize cross-sectoral policies – Policies should be harmonized among the three sectors taking into account the interdependencies of resources in order to minimize cross-sectoral conflicts, maximize synergies, and achieve policy objectives using a systems approach. Policy strategies and instruments employed in achieving sectoral goals need to be harmonized to ensure the systematic promotion of mutually reinforcing strategies and instruments and resolve policy conflicts in order to meet the competing demands for resources (Rasul, 2016). It is necessary to develop and coordinate the policy goals and objectives and harmonize them across the three sectors. The main objective of harmonizing policies is to

reach broader social goals of achieving water, energy and food security while minimizing trade-offs and cross-sectoral conflicts and maximizing synergies across the three sectors.

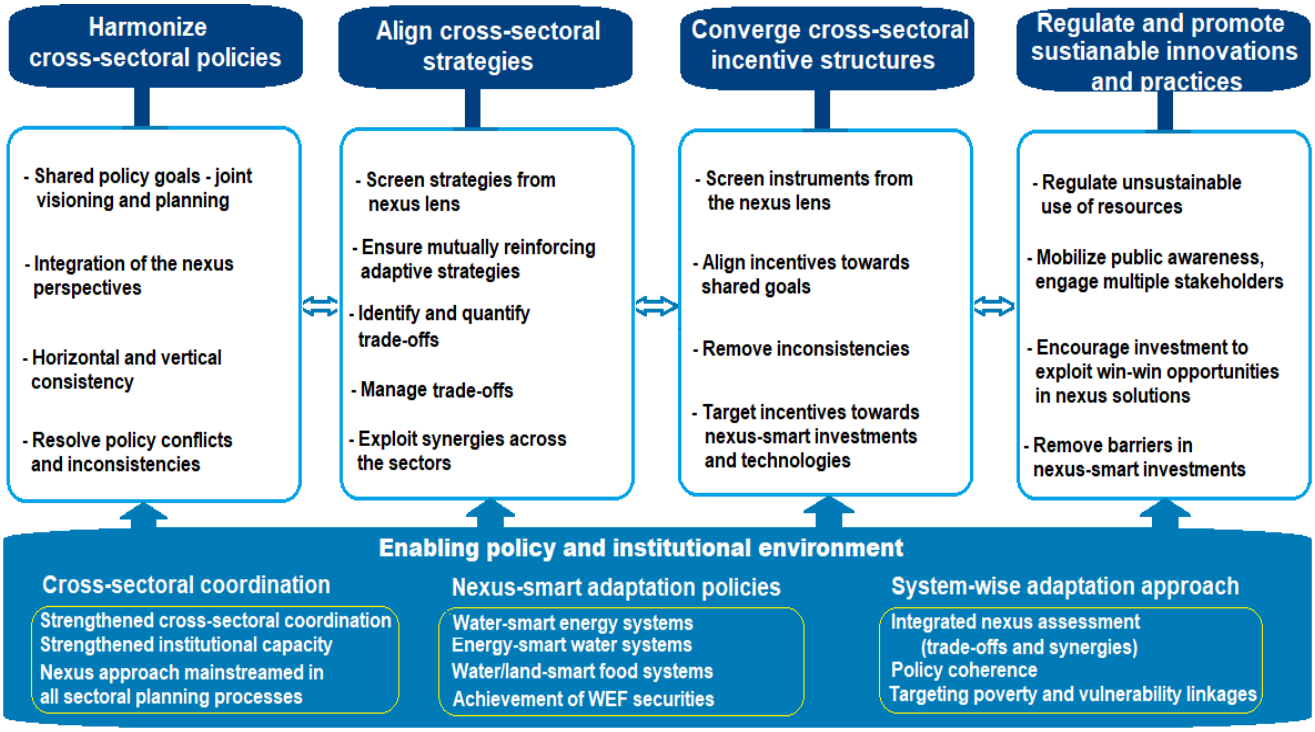


Figure 6.4: Policy framework for managing the WEF-nexus
(Adapted from: Rasul and Sharma, 2015; Rasul, 2016; Mabhaudhi et al., 2019)

Align cross-sectoral strategies – Coordination of strategies across the sectors is essential for exploiting complementarities and synergies and minimizing trade-offs, and for achieving optimal alignment of the strategic objectives. It is necessary to examine strategies in the three sectors from a nexus perspective and identify areas of trade-offs and options for synergies in order to develop and promote mutually reinforcing strategies.

Converge cross-sectoral incentive structures – The incentive structures need to be converged and reoriented towards promoting water and energy-saving technologies and encouraging investment in enhancing the efficiency of water and energy, and away from the policy distortion towards water and energy-intensive food production (Rasul, 2016). It is important to reduce water and energy development subsides, and to cover operating and maintenance costs of water and energy development, to make water and energy development interventions financially viable and environmentally sustainable. Barriers to the adoption of water harvesting, water-efficient technologies, and renewable energy options should be removed.

Regulate unsustainable practices and promote innovations – As food production depends heavily on ground water, and the link between ground water and energy is strong, it is important to establish a ground water management framework to regulate and facilitate the optimal use of ground water in a rational and sustainable manner based on availability and recharge conditions (Rasul, 2016). It is important to raise public awareness and advocate for the responsible use of groundwater resources. Involving farmers in water and energy management is vital for the sustainable use of resources.

Encourage investment in infrastructure development – investment in energy and water-saving technologies and renewable energy options should be encouraged through innovative

policies and institutional support to decouple the intensity of resource use from food production. Enhance the efficiency and productivity of resource use and increase multiple uses of resources through economic incentives, governance, institutional and policy coherence, and the promotion of public-private partnerships to increase the benefit from productive ecosystems (Rasul and Sharma, 2015). Effective strategies should be designed to attract investment to exploit win-win opportunities such as the production and use of renewable energy, for example through hydropower, solar-powered water pumps for irrigation, generation of electricity from crop residues, production of biogas from manure, and introduction of trees or perennials on farms to produce wood for on-farm energy purposes.

Create an interdisciplinary knowledge base – It is important to create an interdisciplinary knowledge base and disseminate knowledge that can offer integrated solutions and a balanced approach for well-informed decision-making guided by the nexus approach. Knowledge and understanding of the interlinkages between the nexus perspective and adaptation plans and responses are limited, so deepening the nexus knowledge base and developing mechanisms to strengthen institutions and internalize this knowledge in the planning process through nexus-based assessment and prioritization is critical for effective and sustainable use of the WEF resources.

6.4.2 Foundation of the policy framework

The enabling environment is the foundation of the framework. The enabling environment provides the foundation for strengthening policy integration between nexus and adaptation mechanisms across sectors at different scales and among the major actors (public-private-civil society partnerships) and strengthening institutional capacity for coordinating the water, energy, and food nexus and adaptation in a holistic way. The elements of the framework foundation effective cross-sectoral coordination, nexus-smart adaptation policies, and system-wise adaptation approach.

Cross-sectoral coordination – Institutional mechanisms for the coordination of policies and actions in the three sectors form the foundations for achieving effective cross-sectoral integration (Weitz et al., 2017). Cross-sectoral coordination is required for managing the interlinkages and attaining WEF securities. In order to address the interdependencies in the WEF nexus, both horizontal (across sectors) and vertical (across scales and levels) coordination is essential (Pahl-Wostl, 2019; Weitz et al., 2017). Strengthening of institutional capacity and mainstreaming of nexus approach in all sectoral planning processes are required. Hence, appropriate mechanisms need to be put in place to strengthen horizontal and vertical integration among the three sectors. This can be achieved through strengthening the role of the national planning commissions or establishing a high-level commission with representatives from the three ministries, think tanks, and civil society with a mandate to oversee the coordination of the three sectors. Strengthening institutional capacity for understanding the dynamics and interlinkages among the three sectors at different scales, and introducing the nexus perspective into planning and implementation, are essential for promoting mutually reinforcing polices and achieving multiple goals (Rasul, 2016). Increasing dialogue among the key actors of the three sectors is also critical.

Nexus-smart adaptation policies: The central area represents the core principles of a nexus-smart policy and the associated outcomes that underpin the three sustainability dimensions. Provide policy and institutional support for attracting investment in green infrastructure and design mechanisms to internalize externalities (environmental and social costs) into decision-making by introducing appropriate incentives, regulations, and payments for ecosystem services.

System-wise adaptation approach: Develop policies which promote a move from a sectoral to a trans-sectoral approach so that different adaptation responses and measures support each other, synergy is enhanced, and trade-offs are minimized.

6.4.3 Applying the policy framework

Sectoral policies are broad strategic directions which are supported by different programs, schemes and instruments (Rasul and Neupane, 2021). Table 6.3 presents an example of an assessment of the major cross-sectoral impacts of sectoral policies. For each sectoral policy, the identified cross-sectoral impacts are entered under each of the three resources, water, energy, and food. Each impact is listed either as a trade-off (-) or a synergy (+).

Table 6.3: Sectoral policies and their cross-sectoral impacts

Sectoral policies*	Cross-sectoral impacts#		
	Water	Energy	Food
P1	(-) or (+)	(-) or (+)	(-) or (+)
P2	(-) or (+)	(-) or (+)	(-) or (+)
P3	(-) or (+)	(-) or (+)	(-) or (+)
P4	(-) or (+)	(-) or (+)	(-) or (+)
P5	(-) or (+)	(-) or (+)	(-) or (+)
P6	(-) or (+)	(-) or (+)	(-) or (+)
P7	(-) or (+)	(-) or (+)	(-) or (+)

* P1, P2: Policy 1, Policy 2, etc.
# (–), sign denotes trade-off; (+), sign denotes synergy.
(Adapted from Rasul and Neupane, 2021)

The policy framework can be used to assess the direction of policy linkages and interactions and identify, quantify and manage trade-offs while at the same time exploiting synergies across the sectors. Table 6.4 presents an example of a qualitative assessment of the different policy options for maximizing complementary effects and minimizing counter-productive impacts with a view to enhancing net societal benefits. The cross-sectoral synergies, trade-offs and neutrality of the policy interactions provide a qualitative and numerical basis for the assessment of policy options (Rasul and Neupane, 2021). Priority should be given to policy options that bring synergistic effects with other strategic objectives and enhance net positive benefits.

Table 6.4: A qualitative assessment of nexus interactions of different policy options and actions

Policy actions*	Cross-sectoral effects#			Other societal and environmental effects (+/-)	
	Water	Energy	Food	Short term	Long term
A1	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-
A2	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-
A3	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-
A4	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-
A5	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-
A6	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-
A7	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-	- or + or +/-

* A1, A2: Policy action 1, Policy action 2, etc.
# + synergetic; -, conflicting; +/-, both positive and negative.
(Adapted from Rasul and Neupane, 2021)

6.5 Conclusions and recommendations

6.5.1 Governance framework

This study presents an operational framework for unpacking WEF governance. The framework has the two-fold aim of providing a harmonised set of governance functions and attributes, and illustrating how the functions and attributes interrelate to achieve specific outcomes. The governance functions seek to capture the key elements and processes that need to be in place

to be able to develop and manage water, energy and food resources and services. Closely linked to the functions are the attributes, which relate to how the functions are implemented. All these functions and attributes are interrelated, all shaped by the values and aspirations of stakeholders. Hence, the framework presents the governance of the WEF resources as a combination of functions, performed with certain attributes, to achieve one or more desired outcomes, all shaped by the values and aspirations of individuals and organisations. As such, the governance of the WEF resources is considered a means to an end rather than an end in itself.

This framework can contribute to an improved understanding of WEF governance in three ways: (i) to understand how in practice (at the national and local level) different functions are linked to certain attributes for achieving desired outcomes, basing the analysis on the proposed framework; (ii) to understand how institutions can self-assess their weaknesses in relation to the framework, and extract general common trends; (iii) to improve governance intervention design as a result of increased understanding of the WEF governance pathway. To illustrate the use of the framework, an analytical approach of assessing the governance attributes is proposed.

It is recommended that the next steps for using this framework are to: (i) further detail operational activities (sub-functions) within and between the core functions, which can allow for more detail in the assessment of governance, as well as for adaptability to different contexts; (ii) to develop practical guidance for how to apply certain attributes when performing WEF governance functions; and (iii) to understand better how working with values and behaviours can improve governance outcomes.

Future research work is needed to assess how best to mainstream IKS innovations and practices into the policy interventions which could increase the suite of WEF smart innovations and practices and policy options for tackling the wicked sustainability challenges across scale. It is recommended that future research work be conducted in order to use the proposed governance framework to assess the performance of governance systems and identify specific governance gaps which need to be addressed.

6.5.2 Policy framework

The proposed policy framework for cross-sectoral coordination in planning and implementing the water-energy-food (WEF) nexus approach is designed to address the interconnections and interdependencies between these sectors. It aims to provide a systematic approach to prioritize policy decisions, actions, and resource allocation across the WEF sectors, as well as foster collaboration within organizations. The framework consists of four key steps:

- ***Harmonizing policy goals:*** This step involves aligning the policy goals of the water, energy, and food sectors to ensure coherence and avoid conflicts. It requires identifying common objectives and areas of overlap among the sectors.
- ***Identifying and mapping sectoral policy interactions:*** In this step, the interactions between sectoral policies are identified and mapped. This includes understanding how policies in one sector can impact or be impacted by policies in another sector. The goal is to gain a holistic understanding of the interconnections and potential synergies or trade-offs.
- ***Assessing compatibility with nexus objectives:*** The compatibility of sectoral policies and strategies with nexus objectives is evaluated in this step. The focus is on identifying the extent to which sectoral policies contribute to or hinder the achievement of WEF nexus goals. This assessment helps prioritize policies and strategies that are in line with the overarching objectives of the nexus approach.
- ***Identifying smart strategies for synergies:*** The final step involves identifying smart strategies that can bring synergistic effects across the water, energy, and food sectors. This includes exploring innovative approaches, technologies, and policies that can

optimize resource use and enhance efficiency. The aim is to find strategies that maximize co-benefits and minimize trade-offs among the sectors.

Throughout the application of the framework, three broad criteria – synergies, trade-offs, and neutrality – are used to assess the impacts of policies and strategies. Synergies refer to the co-benefits that can be achieved by integrating efforts across sectors. Trade-offs represent the externalities or conflicts that may arise when pursuing goals in one sector at the expense of another. Neutrality refers to the avoidance of negative impacts or biases towards any particular sector.

To operationalize the framework, a common cross-sectoral coordination body is recommended. This coordination body would be responsible for implementing the four-step framework, facilitating consultation and dialogue among the sectors, and fostering consensus on prioritizing activities. The aim is to break down sector-specific silos and promote collaboration and alignment of policies and strategies.

By adopting this framework and applying it rigorously, decision-makers can develop a long-term, concerted, and sustained strategy to achieve resource security and address the complex challenges at the water-energy-food nexus.

7 CHAPTER 7: INTEGRATING THE WEF NEXUS INTO POLICY AND GOVERNANCE SYSTEMS: CHALLENGES AND OPPORTUNITIES

7.1 Introduction

The synergies and trade-offs between the water, energy, and food sectors are represented by the Water-Energy-Food Nexus. The Nexus Approach is an integrated decision-making practice that can be used by policy makers to optimize these synergies and manage trade-offs. Implementation of the WEF Nexus approach faces a number of challenges, which can vary depending on country situations and geography. However, governance issues are the most challenging, including a lack of policy coherence, institutional coordination and information, as well as stakeholder power differences and politics at different levels. Another concern is that despite a strong gender dimension in the WEF sectors, gender aspects are often overlooked in the use of the WEF Nexus approach (UN, 2018).

7.2 Integrating the WEF nexus in policy and decision making

Policies create the enabling environment for implementation of the WEF nexus innovations and practices. The study has shown that there are various water-energy-and food/agriculture-related innovations and practices in the study area. The findings of the study have also shown that there are numerous indigenous innovations and practices in the form of IKS. The implementation of WEF nexus practices by local communities and households is limited by some factors which include limited policy support. The policy analysis in Chapter 5 has shown has, while there are policies in the WEF sectors, most of this policies are sector-based with limited support for the utilization and management of the other WEF resources. The study has shown that there is limited integration and coherence between different sectoral policies, as well as limited coordination between key stakeholders, which make it challenging to address the pressing issues related to the management of WEF resources.

7.3 Integrating the WEF nexus in the water, energy and agriculture/food governance

South Africa has three levels of governance: the national, provincial, and local governments. All three levels of government – as well as a variety of role players and stakeholders – must collaborate to achieve and maintain good governance and deliver public services. At community and household levels, the main governance institutions are national, provincial and local governments, CBOs, NGOs, CSOs, WUAs, SACCO, and private services suppliers. As the country is witnessing rapid growth, which also means increased consumption of goods and services per capita, a focus on resource-use efficiency and good governance will ensure adequate, inclusive and sustainable supply of water, energy and food under these circumstances.

The study findings show the integration and coordination of these governance systems is not strong enough to provide enough support for the communities and households in the effective and sustainable management and utilization of WEF resources.

7.4 Challenges in integrating policies, and governance systems in effective implementation of the WEF nexus solutions

One of the challenges communities face in the study area is the apparent limited support offered by national legislation, policies, and strategies for WEF nexus approach. There is more to be done to integrate WEF nexus principles in national and sectoral legislation, policies and strategies. The other challenge is that communities have limited knowledge and understanding of the nexus nature of the WEF resources they manage and utilise. Successful implementation of the WEF nexus approach at local and household levels depend on, among other things, the communities' understanding of the extricate connectivity and linkages of the WEF resources, and hence their understanding of the synergies and trade-offs which exist as they manage and use the resources. The limited information undermines evidence-based decision-making. This is frequently owing to the lack of reliable and up-to-date data on the

status of the WEF sectors, as well as insufficient awareness of the benefits of using the WEF Nexus approach by relevant sector players and inadequate accounting of externalities due to low or no pricing of water and energy use, particularly in developing countries (UN, 2018). In this study, it was shown that there is limited knowledge and information about WEF nexus benefits at community and household levels.

The results of the analysis of degree of support of the legislation, policies, and strategies for the WEF nexus approach show that the complex collaboration between interconnected sectors, diverse sectoral institutional frameworks and interests, insufficient governance frameworks, and a lack of incentive to collaborate with multiple stakeholders from many disciplines and government levels are some of the challenges that must be overcome in order to improve WEF nexus approach. Some of the sectoral policies and strategies do not explicitly support the WEF nexus approach in their design and implementation.

7.5 Opportunities in integrating policies, and governance systems in effective implementation of the WEF nexus solutions

Policies that decouple economic and population growth from resource use and enable transition to a more circular economy have the potential of providing the enabling environment for achieving the sustainability targets in the country.

Unless we achieve changes at household level for example through the changes in management and allocation of resources in the WEF nexus to exploit synergies and reduce trad-offs, one can conclude that the current study has limited impact. However, the study will contribute in other ways, such as learning and awareness-raising through improved understanding of the WEF nexus elements and their interactions within the local system.

The study was primarily aimed at addressing local challenges of implementing WEF nexus approach which likely contributes to a policy-action-driven approach. This approach would lead to practical actions such as the revision of the water allocation rules and financial support for upstream and downstream natural infrastructures to improve WEF synergies and benefits. Furthermore, has also provide some solution of improving implementation of WEF nexus practices at community and household levels.

To achieve needed policy changes identified in the WEF this study, it requires changes in the governance systems relevant for the WEF nexus sectors and the effective coordination of these systems. This could mean for example bringing together agencies and departments that manage critical WEF nexus sectors and/or implement well-defined changes in a governance system to streamline coordination and decision-making procedures across several WEF sectors. For example, to maximize synergies of water use between different users an effective governance system needs to be in place that makes timely and science-based decisions involving all the critical agencies. In practice, this could mean revising existing governance systems by for example adding additional agencies and/or creating processes to make and implement decisions.

The findings of the study suggest that success in implementation WEF nexus-relevant policies depends on the extent to which not just individual policy-makers but also relevant institutions and agencies covering the critical sectors have opportunities for collaboration and involvement in the policy reform. This requires setting up partnerships and/or collaborative agreements with institutions and agencies involved in policy and decision-making to create a basis for shaping the focus of the WEF nexus practices and for the successful and effective uptake of such practices.

The existence of IKS provide great opportunities for the authorities to develop policies and governance systems that support and promote successful indigenous-base WEF nexus practices at community and household levels. Given the nature of the WEF Nexus (i.e. cross-sectoral and focused on key resources for people's livelihoods), ensuring policy coherence and good governance are crucial for its sound and fair implementation.

7.6 Capacity development and knowledge dissemination

Apart from conducting research, the project also involved building capacities of students who were recruited to work on the project. The other aspects of capacity building involved building the capacities of communities where the project was conducted, and the capacities of participating institutions. Knowledge generated from the research was disseminated through peer reviewed papers, and a paper presented at a symposium. The details of capacity development and knowledge dissemination are presented in Appendix 2.

8 CHAPTER 8: GENERAL CONCLUSIONS, INNOVATIONS, RECOMMENDATIONS AND FUTURE RESEARCH WORK

The study set out to conduct context-specific literature search (i.e. desktop study) to expand knowledge base on WEF nexus and establish the current level of WEF nexus resource usage in the study area, to assess suitable WEF smart innovations and practices for the study area, to assess how the existing policy, governance and institutions systems affect implementation of the WEF nexus approaches at household level, and to develop or identify a framework for improving policy, governance and institutional structures in order to support effective implementation of WEF nexus innovations and practices at household level in the study area.

This outcome of the study support attainments of the broader goals of united nations' SDGs, the Africa Union Agenda 2063 and the South Africa NDP 2030 vision, ensuring that economic growth, social equity, and environmental protection are all taken into account.

8.1 Conclusions

A review was conducted on the body of literature that covers areas such as global perspectives of WEF nexus, the need for WEF nexus solutions, WEF nexus interlinkages and frameworks, the WEF nexus research in South Africa, WEF nexus innovations and practices, policy and governance and institutional dimensions of WEF nexus and the application of WEF nexus solutions at the household and community levels. The review findings show that there are various methods and approaches for conducting research on the WEF nexus approach. The current research benefited from the wide range of approaches and methods various researchers have used to study the WEF nexus approach. These approaches provided the basis for developing the methodology for the current study. The literature review findings also highlighted the need to understand the existing and potential WEF nexus innovations and practices applied at the household and community levels and how existing policies and governance systems affect the use and management of WEF resources at these levels.

The study identified Smart WEF innovations and practices in VDM. There exist several innovations and practices across the WEF resource sectors with IKS accounting for the majority of innovations and practices yet being accorded less attention. Mainstreaming IKS innovations and practices into the policy interventions could thus increase the suite of WEF smart innovations and practices and policy options for tackling the wicked sustainability challenges across scale. However, a life cycle assessment of particular innovations and practices may be required to quantify actual environmental footprints. Therefore, there is a need to conduct transdisciplinary research to test and validate the promising WEF nexus innovations, technologies and practices using co-creation approaches (including IKS);

The study aimed to contribute to policy and decision-making processes, and support the adoption of nexus innovations and practices and enhance the sustainability and resource security of each component system in the Nzhelele and Luvuvhu river catchment areas of the VDM in the Limpopo Province of South Africa. The barriers and enablers to adoption identified here as well as policy and governance gaps identified will go along in pursuit of the nexus agenda. The interrelation of the nexus resources can be visualised from their importance, use and chain impact. To a greater extent, the communities are able to link the WEF resources and the chain impact. Several barriers at policy and informational levels as the socio-economic challenges such as poverty undermine the WEF nexus implementation. This will require collaborative institutional and governance approaches as the challenges are cross-cutting. In particular, knowledge, informational and financing barriers need to be accorded greater attention. The use of innovation platforms may greatly increase synergy. This is also to streamline the governance structures, and institutional arrangements in the planning implementation, monitoring and evaluation of WEF nexus problems and objectives.

The analysis of the degree of support of the legislation, policies, and strategies for the WEF nexus approach shows that the Constitution provides solid support for the WEF nexus approach. However, there is a complex collaboration between interconnected sectors, diverse sectoral institutional frameworks and insufficient governance frameworks that must be overcome to improve the WEF nexus approach at the sectoral level. Another challenge is a lack of incentive to collaborate with multiple stakeholders from many disciplines and government levels. Some of the sectoral policies and strategies do explicitly support the WEF nexus approach in their design and implementation. These are challenges which must be overcome in order to achieve the best out of the nexus approach.

The study has identified two main areas which must be addressed. The first area is the apparent limited support offered by national legislation, policies, and strategies for the WEF nexus approach. There is more to be done to integrate WEF nexus principles in national and sectoral legislation, policies and strategies. The second area is that communities have limited knowledge and understanding of the nexus nature of the WEF resources they manage and utilise. Successful implementation of the WEF nexus approach at local and household levels depends on, among other things, the communities' understanding of the extricate connectivity and linkages of the WEF resources, and hence their understanding of the synergies and trade-offs that exist as they manage and use the resources. The results of the study show that there is more to be done to enhance communities' knowledge and understanding of these basic linkages among the WEF resources. In order to improve synergetic solutions between the systems in which resources and activities are arranged to provide final services for the community, communities need to be aware of the nexus perspective. Given the increasing understanding of the inter-connectedness between the systems, conventional perspectives dealing with the systems separately would not be seen as effective even from each system itself and the sustainability aspect of the community.

This study presents an operational framework for unpacking WEF governance. The framework has the two-fold aim of providing a harmonised set of governance functions and attributes, and illustrating how the functions and attributes interrelate to achieve specific outcomes. The governance functions seek to capture the key elements and processes that need to be in place to be able to develop and manage water, energy and food resources and services. Closely linked to the functions are the attributes, which relate to how the functions are implemented. All these functions and attributes are interrelated, all shaped by the values and aspirations of stakeholders. Hence, the framework presents the governance of the WEF resources as a combination of functions, performed with certain attributes, to achieve one or more desired outcomes, all shaped by the values and aspirations of individuals and organisations. As such, the governance of the WEF resources is considered a means to an end rather than an end in itself.

This framework can contribute to an improved understanding of WEF governance in three ways: (i) to understand how in practice (at the national and local level) different functions are linked to certain attributes for achieving desired outcomes, basing the analysis on the proposed framework; (ii) to understand how institutions can self-assess their weaknesses in relation to the framework, and extract general common trends; (iii) to improve governance intervention design as a result of increased understanding of the WEF governance pathway. To illustrate the use of the framework, an analytical approach of assessing the governance attributes is proposed.

8.2 Innovation report

The study has identified several innovations and practices across the WEF resource sectors. Indigenous knowledge system account for the majority of the innovations and practices in the study. However, the IKS require great push in order for the communities to benefit from them. Hence, mainstreaming IKS innovations and practices into the policy interventions could thus increase the suite of WEF smart innovations and practices and policy options for tackling

sustainability challenges across scales. There are various smart innovations for managing and utilizing water, energy, and food/agricultural resources. The greater impact of these innovations lies in scaling out which is about impacting greater numbers through replication and dissemination, increasing the number of people or communities impacted, scaling up to change the rules of the game, and in scaling deep which relates to the notion that durable change has been achieved only when people's hearts and minds, their values and cultural practices, and the quality of relationships they have, are transformed.

The study has developed policy and governance frameworks and are innovative tools for assessing policy and governance relevance for supporting WEF nexus practices in the country. The value of these innovative frameworks lies in operationalizing them as successful implementation of the WEF nexus approach at local and household levels depend on, among other things, the existence of enabling environment provide by good policy and governance systems.

8.3 Recommendations

A holistic water, energy and food security system requires a detailed life cycle assessment evaluation impact assessment of the available suit of WEF innovations and practices alongside an assessment of policy and governance framework impacting them to evaluate the smartness of such innovations and thus inform policy on appropriate WEF smart interventions.

The innovations and practices found to be working within the local context and are promising should be taken to scale. The greater impact can be achieved through:

- "Scaling out", which is about impacting greater numbers through replication and dissemination, increasing the number of people or communities impacted.
- Changing institutions, policy and law – "scaling up" to change the "rules of the game".
- Strategies for "scaling deep" related to the notion that durable change has been achieved only when people's hearts and minds, their values and cultural practices, and the quality of relationships they have, are transformed.

The following recommendations were made based on the results of the study:

- Conduct transdisciplinary research to test and validate the promising WEF nexus innovations, technologies and practices using co-creation approaches (including IKS);
- Integrate WEF nexus in national and sectoral legislation, policies and strategies to enhance the support of these to the implementation of the WEF nexus approach in communities;
- Support multi-stakeholder forums to operationalise a sector-wide approach to addressing the barriers and creating an enabling environment for WEF coordination and adoption, especially with respect to financing, addressing policy bottlenecks and information dissemination and smart WEF technology diffusion;
- Strengthen multi-level and cross-level WEF coordination mechanisms;
- Review of institutional frameworks to align itself with the WEF agenda and cross-cutting issues such as financing;
- Strengthening WEF nexus policies, strategies and regulations, implementation, monitoring and evaluation;
- Improve the coordination of multilevel and cross-level actors;
- Enhance the effectiveness of communication channels (electronic, digital and print as well as social media) to enhance their impact on knowledge dissemination and address the weakness in extension and advisory services;
- Explore innovation platforms as vehicles for dissemination, innovation, and extension and advisory service delivery;
- Conduct public information and awareness campaigns on sustainable WEF innovations and practices; and

- Engage in policy advocacy on existing WEF policies, strategies and regulations and their enforcement.

It is recommended that the next steps for using the governance framework are to: (i) further detail operational activities (sub-functions) within and between the core functions, which can allow for more detail in the assessment of governance, as well as for adaptability to different contexts; (ii) to develop practical guidance for how to apply certain attributes when performing WEF governance functions; and (iii) to understand better how working with values and behaviours can improve governance outcomes.

The results of the analysis of degree of support of the legislation, policies, and strategies for the WEF nexus approach show that the complex collaboration between interconnected sectors, diverse sectoral institutional frameworks and interests, insufficient governance frameworks, and a lack of incentive to collaborate with multiple stakeholders from many disciplines and government levels are some of the challenges that must be overcome in order to improve WEF nexus approach. Some of the sectoral policies and strategies do not explicitly support the WEF nexus approach in their design and implementation.

The proposed policy framework for cross-sectoral coordination in planning and implementing the water-energy-food (WEF) nexus approach is designed to address the interconnections and interdependencies between these sectors. It aims to provide a systematic approach to prioritize policy decisions, actions, and resource allocation across the WEF sectors, as well as foster collaboration within organizations. The framework consists of four key steps namely harmonizing policy goals, identifying and mapping sectoral policy interactions, assessing compatibility with nexus objectives, and identifying smart strategies for synergies. Throughout the application of the framework, three broad criteria – synergies, trade-offs, and neutrality – are used to assess the impacts of policies and strategies. Synergies refer to the co-benefits that can be achieved by integrating efforts across sectors. Trade-offs represent the externalities or conflicts that may arise when pursuing goals in one sector at the expense of another. Neutrality refers to the avoidance of negative impacts or biases towards any particular sector.

To operationalize the framework, a common cross-sectoral coordination body is recommended. This coordination body would be responsible for implementing the four-step framework, facilitating consultation and dialogue among the sectors, and fostering consensus on prioritizing activities. The aim is to break down sector-specific silos and promote collaboration and alignment of policies and strategies. By adopting this framework and applying it rigorously, decision-makers can develop a long-term, concerted, and sustained strategy to achieve resource security and address the complex challenges at the water-energy-food nexus.

The findings of the study suggest that success in implementation WEF nexus-relevant policies depends on the extent to which not just individual policy-makers but also relevant institutions and agencies covering the critical sectors have opportunities for collaboration and involvement in the policy reform. This requires setting up partnerships and/or collaborative agreements with institutions and agencies involved in policy and decision-making to create a basis for shaping the focus of the WEF nexus practices and for the successful and effective uptake of such practices.

8.4 Future research work

Future research work is needed to assess how best to mainstream IKS innovations and practices into the policy interventions which could increase the suite of WEF smart innovations and practices and policy options for tackling the wicked sustainability challenges across scale.

- It is recommended that future research work be conducted in order to use the proposed governance framework to assess the performance of governance systems and identify specific governance gaps which need to be addressed. Further, there is a need to conduct transdisciplinary research to test and validate the promising WEF nexus innovations, technologies and practices using co-creation approaches (including IKS);

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APPENDICES

Appendix 1: Data collection Tool

INTEGRATING WATER-ENERGY-FOOD NEXUS INNOVATIONS AND PRACTICES INTO POLICY, GOVERNANCE AND INSTITUTIONAL FRAMEWORKS FOR SUSTAINABLE DEVELOPMENT IN VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

QUESTIONNAIRE

RESEARCH DECLARATION

I certify that this interview took place with full consent of the recorded respondent and that the information contained in this questionnaire is an accurate reflection of his/her views.

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Name of Interviewer	**Signature**	**Date**

Section 1: Interview Details

This Section is designed to gather information about the study respondents (and/or participants). Respondents are those persons who will be invited to participate in this research study and have actually taken part in the study.

Numbering	Required to fill-in/Question	Instruction
	Supervisor's Name	Indicate the name of the supervisor
	Enumerator's Name Please Select Your Name	Indicate name of the supervisor
	Supervisor's Check Date	yyyy-mm-dd To be completed by supervisor
	Respondent's Name Name of the Respondent	Type in Name and Surname
	Respondent's Household (HH) Status	Choose from: - Household Head - Spouse - Child - Relative
	Gender of the Head of the Respondent	Choose from: - Male - Female - Prefer not to say
	Age category of the Respondent	Choose from: - 20 and under - 21-30 - 31-40 - 41-50 - 51-60 - Above 60
	Highest Education Level of the Respondent	Choose from: - No schooling - Primary Education - Secondary Education - TVET/College Education

Numbering	Required to fill-in/Question	Instruction
		- University Education
	Employment Status of the Respondent	Ask if the respondent is employed: - Yes - No
		If YES, type in the form of employment[14] (i.e. teacher, nurse, shop steward, etc.)
		Also, indicate if it is[15]: - Formal - Informal

Section 2: Demographic Information (Household Typology)

The collected demographic information in this Section will allow the Research Team to better understand certain background characteristics of an audience, whether it's their age, race, ethnicity, income, work situation, marital status, etc.

Numbering	Required to fill-in/Question	Instruction	
	Indicate Village Location	Municipality ward within Vhembe with refence to pilot site	
	Indicate Village Name	Village with refence to pilot site	
	How many members live in this household including you?	Choose from pre-programmed numbers	
	Household Physical Assets: What are the assets within the household? ➔ Select = ticking from pre-programmed list. Multiple entries are allowed.	Select water related assets	
		Select energy related assets (i.e. what does the HH use for lighting): - Firewood - Battery powered light/lamp - Paraffin - Electricity - Solar - Generator - *Other, name:*	
		Select agriculture production related assets	
		Crops: - Spade - Digging fork - Rake - Han Hoe - Home ox-drawn farm implements (e.g. plough, cultivator, ridger, cart) - Tractor - Home garden	**Livestock:** - Chickens - Commercial Poultry - Small stock – goats - small stock – sheep) - - Cattle – Beef - Cattle Dairy

14 Employment means the state of having a paid job.
15 Formal employment is recognised of workers with social security benefits provided by the employer, while informal employment refers to its absence.

Numbering	Required to fill-in/Question	Instruction	
		- Field within HH - Filed outside HH - Commercial orchard - *Other, name:*	- *Other, name:*
		Food storage, processing or preservation (i.e. post-harvest loss management): - Fridge/Freezer - Stove (charcoal, firestone, biogas, paraffin, electricity) - Sun drier - Grinder/ HH miller - Household grain storage facility - *Other, name:*	
		ICT/Information access and related assets: - Telephone line - Cell phone Network Access - TV - Radio	
	Indicate other WEF related assets, if any.	Type in as required ➔ Multiple entries are allowed.	

Section 3: A Typology of the WEF Nexus

The purpose of this Section is to characterize the Water, Energy and Food (Agriculture) nexus elements. To provide context, in this Section, we will collect data to assist describe concretely what is happening (i.e. the current situation of the WEF elements within the pilot sites). This will then make it easy for the reader to have a better understanding of the background and the results of the research.

Section 3.1: Typology of Household Water Uses

Numbering	Required to fill-in/Question	Instruction
	Indicate the source of household water? ➔ some questions will have sub-questions.	Choose from (multiple entries allowed): - Household Municipal Tap - Communal Municipal Tap - Household Borehole *(➔ indicate the source of energy used pump water*) - Communal Borehole *(➔ indicate the source of energy used pump water*) - Fountain - River steam *(➔ indicate the mechanism used to draw or transfer water*) *Other, name:*
	For each selected source, indicate water sanitation and quality method.	Choose from: - Household boiling - Household chlorine treatment - Central chlorine treatment - *Other, name:*
	For each selected source, indicate if water is paid for.	Choose from: - Paid - Not paid
	For each selected source, indicate location/distance to water source.	Choose from: - Within the HH - Within 1 KM of the HH - Beyond 1 KM of the HH
	Indicate the main use of water by the household	Choose from: - HH consumption and use - Vegetable husbandry - Livestock husbandry - Other commercial activity, name:
	Indicate consistency of water supply (if there are cut off) affection WEF nexus	Are cut-off happening: - Daily - Once a week - Once a month - Never
	Other, please specify	

Section 3.2: Typology of Household Energy Uses

Numbering	Required to fill-in/Question	Instruction
	Indicate the type of household energy used (at HH level and/or field outside the HH)	Choose from -
	For each selected type, indicate the source/supplier of each.	Choose from -
	For each selected source, source indicate if that energy is paid for.	Choose from: - Paid - Not paid
	For each selected type, indicate the main use of each mentioned energy type.	Choose from -
	Indicate if there are any energy supply disruptions that affect WEF nexus	Choose from: -
	Other, specify	

Section 3.3: Typology of Household Agriculture Farming Systems

Numbering	Required to fill-in/Question	Instruction
	Agro-ecological zone	Choose from

	Crop Farming System	- Type of Crops; for each:
		- Form of production
		  o Irrigated/Dryland
		  o Inside/outside homestead
		  o Subsistence/commercial
		  o Labor provision (HH/hired)
		- Post-harvest activities
		  o Form of storage
		  o Form of value-addition
		  o Form of preservation
		- Marketing channels
		- The importance of water to the farming system
		- Importance of energy to the farming system
		- Total size of land

	Horticulture Farming System	- Type of fruit trees farmed, for each: - Production system - Intensive/extensive - Subsistence/commercial - Labor provision (HH/hired) - Marketing channels - The importance of water to the farming system - Importance of energy to the farming system - Total size of land

	Livestock Farming System	- Type of livestock farmed, for each:
		- Production system
		  o Intensive/extensive
		  o Subsistence/commercial
		  o Labor provision (HH/hired)
		- Marketing channels
		- The importance of water to the farming system
		- Importance of energy to the farming system

Numbering	Required to fill-in/Question	Instruction
		- Herd sizes
	Other, please specify	

Section 3.4: Typology of Food Security and Food Sufficiency

Numbering	Required to fill-in/Question	Instruction
	Food Security	
	"I worried whether our food would run-out."	Please for each statement/question whether the statement/question was often, sometimes, or never in the last 12 months. Choose from: - Often - Sometimes - Never
	“The food that we produced just didn't last, and we didn't have money to get more."	
	“We couldn't afford to eat balanced meals."	
	"We couldn't feed the children a balanced meal because we couldn't afford that."	
	In the last 12 months, did you ever eat less than you felt you should because there wasn't enough food?	
	In the last 12 months, were you ever hungry but didn't eat because there wasn't enough food?	
	In the last 12 months, did you or other adults in your household ever not eat for a whole day because there wasn't enough money for food?	
	In the last 12 months, did you ever cut the size of any of the children's meals because there wasn't enough food?	
	Food Sufficiency	
	Which of these statements best describes the food eaten in your household in the last 12 months?	Please read the statements and ask the respondent to select his/her best choice - We always have enough to eat and the kinds of food we want; - We have enough to eat but not always the kinds of food we want; - Sometimes we don't have enough to eat; or - Often, we don't have enough to eat?
	Here are some reasons why people don't always have enough to eat. For each one, please tell me if that is a reason why You don't always have enough to eat.	Multiple responses allowed - Agriculture low production - Agriculture post-harvest loss - Not enough money/income for food - Lack of water - No access to cooking energy source

Numbering	Required to fill-in/Question	Instruction
		- Too hard to get to the store - Drought - Theft - Not able to cook or eat because of health problems; - Other, name

Section 4: WEF Technological Innovations and practices

In the specified field: 1) Indicate the WEF technological innovations and practices use are currently using; 2) indicate how you are using them, 3) mention the related benefits, and 4) mention the related challenges.

The purpose this Section is to understand each WEF components and relationships among the component parts found within the WEF system. This will help explain, better understand, and explore research subjects' opinions, behavior, experiences, phenomenon, etc.

Section 4.1: Water Technological Innovations and Practices

Numbering	Water technological Innovation and Practices Choose from the list as dictated by the respondent		Details about the utilized technological Innovation and Practices (Required to fill-in/Question)			Prioritization[16]
	Indicate the sub-category as per WEF nexus	Utilized technological Innovation and Practices	Indicate how you are using the Water technological Innovation and Practice	Give us the reasons why you are using the technological Innovation and Practice	Give us the challenges you are experiencing using the technological Innovation and Practice	Rank the perceived benefit of the technological Innovation and Practice
	Rainwater	Water harvesting using large dams				
		Water harvesting using small dams (i.e. for agriculture)				
		Household storage (e.g. JoJo tanks).				
	Underground Water	Water detection: XXX technologies (i.e. Allen technology)				

16 The Likert scale used to prioritize the WEF identifies technological Innovation and Practice is: 1 = very poor, 2 = poor, 3 = neutral, 4 = good, 5 = excellent

Numbering	Water technological Innovation and Practices Choose from the list as dictated by the respondent		Details about the utilized technological Innovation and Practices (Required to fill-in/Question)			Prioritization[16]
	Indicate the sub-category as per WEF nexus	Utilized technological Innovation and Practices	Indicate how you are using the Water technological Innovation and Practice	Give us the reasons why you are using the technological Innovation and Practice	Give us the challenges you are experiencing using the technological Innovation and Practice	Rank the perceived benefit of the technological Innovation and Practice
		Water drawing: Wind/Solar powered boreholes				
		Artificial Groundwater recharge into confined aquifers for future use				
	Water Recycling	Wastewater Treatment with Effective Microorganisms (EM) (i.e. Photosynthetic bacteria, Lactic acid bacteria, Yeast)				
	River streams	Digital water monitoring using satellite images – Ability to track in- and out-flows.				
	Reducing water loss	Maintenance of bulk water storage and distribution networks				

Numbering	Water technological Innovation and Practices Choose from the list as dictated by the respondent		Details about the utilized technological Innovation and Practices (Required to fill-in/Question)			Prioritization[16]
	Indicate the sub-category as per WEF nexus	Utilized technological Innovation and Practices	Indicate how you are using the Water technological Innovation and Practice	Give us the reasons why you are using the technological Innovation and Practice	Give us the challenges you are experiencing using the technological Innovation and Practice	Rank the perceived benefit of the technological Innovation and Practice
		(e.g. infrastructure routine maintenance and use call centers to log/report leaks for timely repairs) Promoting use of water saving devices in institutions and households (e.g. washing machines, showers, toilet systems)				
	Watergen technology	A solution that uses humidity in the air to create clean and fresh drinking water				
	Other indigenous innovations and practices					

Section 4.2: Agriculture and Food Technological Innovations and Practices

Numbering	Food and Agriculture Innovation and Practices Choose from the list as dictated by the respondent		Details about the utilized technological Innovation and Practices (Required to fill-in/Question)			Prioritization
	Indicate the sub-category as per WEF nexus	Utilized technological Innovation and Practices	Indicate how you are using the Water technological Innovation and Practice	Give us the reasons why you are using the technological Innovation and Practice	Give us the challenges you are experiencing using the technological Innovation and Practice	Rank the perceived benefit of the technological Innovation and Practice
	Conservation agriculture	• Zero cultivation • Mulching, etc.				
	Smart irrigation	- Drip irrigation - using handheld devices to measure soil moisture (chameleon technology)				
	Sustainable intensification	use of: - tunnels, - hydroponics - aquaponics				
	Use of disaster related insurance	Index-based insurance (for floods) (e.g. http://ibfi.iwmi.org/ by IWMI).				
	Behaviour Change Interventions	- Innovation platforms - WEF Trainings				

Numbering	Food and Agriculture Innovation and Practices Choose from the list as dictated by the respondent		Details about the utilized technological Innovation and Practices (Required to fill-in/Question)			Prioritization
	Indicate the sub-category as per WEF nexus	Utilized technological Innovation and Practices	Indicate how you are using the Water technological Innovation and Practice	Give us the reasons why you are using the technological Innovation and Practice	Give us the challenges you are experiencing using the technological Innovation and Practice	Rank the perceived benefit of the technological Innovation and Practice
	Other indigenous innovations and practices					

Section 4.3: Energy Innovations and Practices

Numbering	Energy Innovation and Practices Choose from the list as dictated by the respondent		Details about the utilized technological Innovation and Practices (Required to fill-in/Question)			Prioritization
	Indicate the sub-category as per WEF nexus	Utilized technological Innovation and Practices	Indicate how you are using the Innovation and Practice	Give us the reasons why you are using the technological Innovation and Practices	Give us the reasons why you are using the technological Innovation and Practices	Rank the perceived benefit of the Water technological Innovation and Practices
	Biogas digester	-				
	Electricity	-				
	Firewood	-				
	Paraffin	-				
	LPG / Gas	-				
	Coal	-				
	Solar	-				
	Other indigenous innovations and practices	-				

Section 4.4: Membership in local institutions

What institutions are there which affect or influence your use and management of water, energy, and food production in your household/community? (**Please list)**

WEF sector	**Institutions(Name as many)**
Water	
Energy	
Food production	

Section 4.5: Membership in local institutions

Institution (Are you a member in any of the following?)	Yes	No
Water Users Association		
Savings and credit society		
Micro credit finance		
Any other Interest Group (Name it)		

Section 4.6: Governance actors and their role in WEF

WEF sector	Actor (As many actors as there could be)	Role (Tick against the role for each of the actor)
Water		Regulatory (Licensing/ permits) Advocacy Supplier Financing Training/ Awareness creation Policy Capacity building Advocacy /lobbying Conflict resolution Sustainability and resilience building
Energy		Regulatory (Licensing/ permits) Advocacy Supplier Financing Training/ Awareness creation

WEF sector	Actor (As many actors as there could be)	Role (Tick against the role for each of the actor)
		Policy Capacity building Advocacy /lobbying Conflict resolution Sustainability and resilience building
Food production /Irrigation and land use		Regulatory (Licensing/ permits) Input Supplier Financing Training/ Awareness creation Policy Capacity building Advocacy /lobbying Conflict resolution Sustainability and resilience building

Section 4.7: WEF resource use

WEF Resource	Type and source	Amount used per day/ month/ season/ year/ crop cycle	Specific use for which resource is used
Food/Agriculture	Fruit trees Fodder Vegetables Cereals and pulses Fodder/ pastures		

WEF Resource	Type and source	Amount used per day/ month/ season/ year/ crop cycle	Specific use for which resource is used
	Livestock (poultry)		
Energy	Solar Mains Electricity Wind		
Water	Borehole River Roof Harvesting Dam Surface harvesting		

Section 4.8: WEF Resource access use and use rights

WEF Resource	Dimension	Is any of the dimension in the previous column an issue of concern Yes / NO	If Yes state, the issue (e.g. Permits, metering, rules, rationing for each of the dimensions)	Further comment if any
Water	Source for Domestic use Source for Agricultural use/ irrigation Quantity for Agricultural use/ irrigation			
Energy	Type (Solar, wind, thermal, etc.) Regulation on type to use Reliability of supply Cost of alternatives Access to alternatives			
Land/ food production	Size of land planted Season of planting Crop type Amount of water required and used Time of irrigation Zoning restrictions			

WEF Resource	Dimension	Is any of the dimension in the previous column an issue of concern Yes / NO	If Yes state, the issue (e.g. Permits, metering, rules, rationing for each of the dimensions)	Further comment if any
	Type of livestock kept			

Section 4.9: WEF Financing: Have you received any financing towards any of the following

WEF	Credit source	Yes/No	Specific Purpose on which credit was utilised	Any comment
Water development	Cooperative Bank Microcredit Family Local saving group Grant (specify)			
Energy development	Cooperative Bank Microcredit Family Local saving group Grant (specify)			
Food production	Cooperative Bank Microcredit Family Local saving group Grant (specify)			

Section 5.0: Communication channels and extension on WEF Smart technologies

For each of the information sources provide the frequency you have had in the last one year

Source of information for each WEF	Source of information	Yes/ No	How frequent do you receive the information (for each source)
Energy smart technologies	Public extension Private extension Radio Newspaper Online Peers Scientific publication Autonomous (own effort)		Daily Weekly Monthly Quarterly Biannually Annually
Water Smart technologies	Public extension Private extension Radio Newspaper Online Peers Scientific publication Autonomous (own effort)		
Land use for food production smart technologies	Public extension Private extension Radio Newspaper Online Peers Scientific publication Autonomous (own effort)		

Section 5.1: Players in WEF technology promotion and adoption

Smart technology	Specific WEF smart innovation	Who promotes	Constraints	Rank the constraints named (Use **I** for the most pressing)
Energy	Solar Energy saving Wind Any Other	Public extension Private Extension NGO/ CSO/ CBO Research Organisation Government agency International organisation Autonomous (own effort)	Initial investment cost Maintenance costs Lack of market Lack of knowhow High Cost of alternatives Lack Access to alternatives Any other	
Water use	Water recycling Water harvesting/ roof harvesting Drip irrigation Hydroponics Any other	Public extension Private Extension NGO/ CSO/ CBO Research Organisation Government agency International organisation Autonomous (own effort)	Initial investment cost Maintenance costs Lack of market Lack of knowhow High Cost of alternatives Lack Access to alternatives Any other	
Land use	Manuring Cover crops Mulching Zero tillage Climate manipulation /Green houses Any other	Public extension Private Extension NGO/ CSO/ CBO Research Organisation Government agency International organisation Autonomous (own effort	Initial investment cost Maintenance costs Lack of market Lack of knowhow High Cost of alternatives Lack access to alternatives Any other	

Section 5.2: What has influenced or likely to influence you adopt smart technologies

WEF Technology	Factor	Already influenced? Yes/ no	Likely to influence in future if not using
Energy smart technologies	Knowledge/ education Finance Value for environment Social network Peers Family spillovers Market access Grant High returns Cost saving Reliability		
Water smart Technologies	Knowledge/ education Finance Value for environment Social network Peers Family spillovers Market access Grant High returns Cost saving Reliability		
Land use/ food production smart technologies	Knowledge/ education Access to financing Value for environment Social network Peers Family spillovers Market access Grant High returns Cost saving		

Section 5.3: Barriers to WEF smart technologies

WEF resource	Barrier	Yes / No	Rank the barriers (Use 1 as the most pressing)
Energy smart technologies	Initial cost Technical Knowhow Government regulation and policies Lack of information Lack of capital/ credit Lack of alternatives High cost of alternatives Any other		
Water Smart technology	Initial cost Technical Knowhow Government regulation Lack of information Lack of capital/ credit Lack of alternatives High cost of alternatives Any other		
Land use smart technologies	Initial cost Technical Knowhow Government regulation Lack of information Lack of capital/ credit Any other		

Section 5.4: Policy and institutional support

5.4.1. Rules, regulations, and laws

a) What rules, regulations, and laws* are there which affect or influence your use and management of water, energy and food production in your household/community? (**Please list)**

	Rules	**laws**	**Regulations**
Water	**1.** **2.** **3.**		
Energy	**1.** **2.** **3.**		
Food	**1.** **2.** **3.**		

b) In your opinion what changes need to be made to improve the roles of the rules, regulations, and laws in supporting your effective and sustainable use and management of water, energy and food production in your household/community? (**Please list**)

	Water	Energy	Food production
In your opinion what changes need to be made to improve the roles of the rules, regulations, and laws in supporting your effective and sustainable use and management of other listed resources at household/community?			

5.4.2. Policies

a) What policies are there which affect or influence your use and management of water, energy, and food production in your household/community? (**Please list)**

WEF sector	Current policy	Explain How does each of the listed to the left
Water		
Energy		
Food production		

b) In your opinion what changes need to be made to improve the roles of the institutions in promoting your effective and sustainable use and management of water, energy, and food production in your household/community? (**Please list**)

Institution category	**Energy**	**Water**	**Food production**
Regulatory			
Advisory			
Lobby / advocacy			
Research			
Finance			
Water Users Association			

c) In your opinion what changes need to be made to improve the roles of the policies in supporting your effective and sustainable use and management of water, energy, and food production in your household/community? (**Please list**)

Policy	**Water**	**Energy**	**Food**
1.			
2.			
3.			
4.			
5.			

*** *Rules*** are guidelines and instructions for doing something right. They are created to manage behaviour in an organization or community.[17]

17 https://sanctionscanner.com/blog/what-is-the-difference-between-rules-and-regulations-341

Laws go through the bill process before becoming established as a law. A bill has to be written, sponsored by a legislator, debated and passed through.[18]

Regulations are directives created by a governmental agency, often to actually implement a given law, and do not have to go through the bill process.[19]

To ensure that the proposed mixed model approach is robust enough, Sections 6, 7 and 8 interview questions are open-ended questions so that in-depth information will be collected.

18 https://www.mamhca.org/assets/1/7/Laws_vs_regulations.pdf
19 Ibid

Section 6: WEF Nexus Trade-off and Synergies[20]

Numbering	Required to fill-in/question	Instruction
	What are the trade-offs (even potential completion) experienced while enhancing synergies towards attaining simultaneous WEF resource securities?	Please read the statements and ask the respondent to answer to their best ability.
	What are the synergies required to attain simultaneous WEF resource securities?	
	Practical experience in water, energy and food interlinkages	

Section 7: General Knowledge on WEF Nexus

Numbering	Required to fill-in/question	Instruction
	What is the meaning of WEF nexus approach?	Please read the statements and ask the respondent to answer to their best ability.
	What do you understand by the term water security?	
	What do you understand by the term renewable energy?	
	What do you understand by the term food security?	
	What do you understand by the term sustainability?	

Section 8: Suggested on WEF nexus solutions

Numbering	Required to fill-in/question	Instruction
	What should be done to eradicate water insecurity?	Please read the statements and ask the respondent to answer to their best ability.
	What should be done to eradicate energy scarcity (if any)?	
	What should be done to eradicate food insecurity?	
	What can be done to overcome the barriers impeding WEF nexus operationalisation?	

20 Naidoo et al. (2021) Operationalizing the water-energy-food nexus through the theory of change.

KEY INFORMANT INTERVIEWS SCHEDULE

1. Actor name and mandate

Sector	Actor	Mandate	Instruments and tools on access and use of WEF resources
Energy			Permits Tariffs Education/ informational
Water			
Land and land use			

2. Do you have coordination mechanism with other sectors (named in 1) at local and national levels?
3. Are there community engagement plans in your sector regarding water use/ energy/ land use
4. What are some of the resource conflicts and grievance redress mechanisms about access, use and control of the WEF resources in your sector and how do you resolve them?
5. How is Environmental, social and climate impact assessment integrated into your planning processes
6. How are financing intermediaries integrated into your planning processes?
7. What incentives do you have regarding scaling of climate smart technologies?
8. Do you have partnership with regard to research, implementation and steering of your mandate?
9. What are your intervention and strategies regarding the following?

Sector and actor	Access (poverty and equity)	Sustainability (economic, social, and environmental	Efficiency	Climate change vulnerability (adaptation and mitigation and resilience building)
Water – Water smart energy systems 1. 2. 3.				
Energy – Energy smart water systems 1. 2. 3.				

Land use= Water land smart food systems 1. 2. 3.				

Water Innovations and Solutions and Tools: Water-Energy-Food/Agric nexus

Table 1: Supply-side of Water (i.e. Source and distribution[21,22])

Water Source	Solution/Tool[23]	Benefit	Concerns/Gaps	Energy source
Rainwater	Water harvesting using large dams.	• Provides wider access to water • Opportunity to generate hydro-energy	• Dependent on rainfall, and in recent past dam levels are below required levels. • Intra- and inter-sharing of water sharing challenges. • Lack of distribution and reticulation. • Silting of dams (reducing the water carrying capacity)	• Gravity
	Water harvesting using small dams (i.e. for agriculture)	• Increases "water balance" • Reduce production cost	• Lack of resources to construct these small dams (e.g. by the farming community)	• Gravity
	Household storage (e.g. JoJo tanks). Promoting a national policy that requires each private and commercial property to put in place a water storage of a specific size to harvest rainwater	• Increases "water balance"	• Cost?	• None
Ocean Water	Desalination (thermal, electrical, and pressure distillation)	• Abundance of the ocean water	• How this can be done efficiently • Waste management	• Solar/wind/hydropower
Watergen technology	A solution that uses humidity in the air to	• Abundance of water in the atmosphere	•	• Solar

21 Linking energy nexus, it will require green mini power stations off the grid and biogas for power generation (reduce low emission)
22 A construction and civil engineering companies will be engaged as partners
23 A tool kit box will be developed after proof of concept to allow scaling out and learning

Water Source	Solution/Tool[23]	Benefit	Concerns/Gaps	Energy source
	create clean and fresh drinking water			
Underground Water	Water detection: XXX technologies (i.e. Allen technology)	• Independent from the mains water supply • Borehole water supplies are sustainable in even drought conditions • Independent from the mains water supply – no water charge/cost saving	• Water quality and safety: Contamination of aquafers (e.g. from pit latrines, agriculture (fertilizers, insecticides, etc.) • Over abstraction of the ground water	• Solar/wind/hydropower
	Water drawing: Wind/Solar powered boreholes			• Wind/Solar
	Artificial Groundwater recharge into confined aquifers for future use			
Water Recycling	Wastewater Treatment with Effective Microorganisms (EM) (i.e. Photosynthetic bacteria, Lactic acid bacteria, Yeast)	• Increases “water balance”	• Effectiveness of the water cleaning solution may be questionable	• Solar/Hydropower
River streams	Digital water monitoring using satellite images – Ability to track in- and out-flows.	• Solve water allocation	• Water sharing challenges (upstream v/s downstream conflicts) • Drought • Contamination from industrial waste	• Solar
Reducing water loss	Maintenance of bulk water storage and distribution networks (e.g. infrastructure routine maintenance and use call centers to	• Reduces water loss due to leakages	•	• Solar/Hydropower

Water Source	Solution/Tool[23]	Benefit	Concerns/Gaps	Energy source
	log/report leaks for timely repairs) Promoting use of water saving devices in institutions and households (e.g. washing machines, showers, toilet systems)			

Table 2: Demand-side of water (users)

User type	Solution/Tool	Benefit	Concerns	Energy source
	Local wind/solar energy desalination system for irrigation	• Less burgled to the national grid	• `Maintenance and security issues	• Solar/win
Agriculture	Smart irrigation using handheld devices (chameleon technology)	• Efficient water use	• Accuracy of these technologies	• Solar?
	Sustainable intensification (e.g. use of tunnels, hydroponics and aquaponics)	• Increased agriculture productivity	• Cost to establish	• Solar/wind/hydropower
	Index-based insurance (for floods) (e.g. http://ibfi.iwmi.org/ by IWMI). Can leverage digital weather stations which are becoming accurate and cheaper (and can be used for early warnings).	• De-risking farmers against climate disasters (here flood) • Early warnings for preparedness	• Accuracy of the data • Lack of such products	• Solar
	Innovation platforms	• Long lasting changes due its participatory nature.	Representativeness nature of the Innovation Platforms and power dynamics.	
Household use	Behaviour changes and communication (for attitude towards water use)	• Long lasting changes due its participatory nature.	Sustainability of this changes after implemented BCC interventions	
	Smart use of water (e.g. timed shower, smart flush toilets)	• Reduce household water use and water bill.		
	Community-based decision-making platforms	• Increased ownership due to community participation	Methodology to achieve total but-in is not know	
	Water billing			

User type	Solution/Tool	Benefit	Concerns	Energy source
Other industries				

Appendix 2: Capacity development and knowledge dissemination

(A) Introduction

The project resulted in the development and enhancement of institutional and human capacities. The human capacities related to formal training of students and enhancing capacities of communities in implementing WEF nexus practices. Knowledge dissemination was done through presentation at symposium and publication of articles in journals.

(B) Capacity development

i. Students

The project initially recruited four full-time students who were conducting their MSc research projects on the WEF Nexus Project as part of capacity building. However, one of the students stopped studying, hence, we ended up with three students. The study details of the three students are presented in Table A.1.

Table A.1: Students working on the project

Student	Level of study	Area of study related to the project
Ms Phindulo Mphaphuli	Masters	***Work Package 3:*** Identifying, mapping and assessing WEF nexus innovations and practices
Ms Mulalo Mudau	Masters	***Work Package 3:*** Identifying, mapping and assessing WEF nexus innovations and practices
Ms Lufuno Mabala	Masters	***Work package 4:*** Policy, governance and institutional structures analysis

Comprehensive details of the students are presented in Appendix 3.

ii. Communities

Communities which participated in the study included Siloam, Phadzima, Khalavha, Sambandou and Malavuwe which are within Vhembe District Municipality. Communities gained knowledge on the concept of WEF nexus and how it can benefit, technological innovations and practices (some of which they were already implementing but without realising that they fit with the WEF nexus).

iii. Participating institutions

The capacity of the partner institutions was enhanced through the implementation of the project. The partner institutions were CLOVITA Consulting Services, OZONE Agric Development Solutions, and the University of Venda. The participating institutions shared knowledge on research methodologies and data analysis techniques. The research team also learned a lot about indigenous knowledge systems related to WEF nexus which communities shared.

(C) Knowledge dissemination

A paper was presented at the South African National Committee on Irrigation and Drainage (SANCID) Symposium 21-23 February 2023, Fairview Hotels, Spar and Golf Resort, Tzaneen, Limpopo Province. The title of the paper was "*Water-energy-food nexus innovations and practices under the impact of water scarcity in Vhembe District, Limpopo Province, South Africa*".

The articles which have been produced from the project as part of knowledge dissemination are presented in Table A.2.

Table A.2: Articles produced for publications

Title of Article	Journal Submitted to	Publishing Status
Integrating water-energy-food nexus innovations and practices into policy, governance and institutional frameworks for sustainable development in Vhembe District, Limpopo Province, South Africa: Literature review	International Journal of Food Science and Agriculture (IJFSA)	Published
Assessing policy, governance and institutional systems for water-energy-food nexus: the case of the Vhembe District, Limpopo Province, South Africa	F1000Research	Rejected
An assessment and mapping of Water-Energy-Food nexus innovations and practices in Vhembe District, Limpopo Province, South Africa	Frontiers in Water	Under review

The first page of the published article is presented in Appendix 4.

(D) Conclusions

The project has helped to build capacities of students in terms of conducting research and disseminating research findings to various audiences. The capacity of participating communities and the research partner institutions were enhanced through the implementation of the project. The partner institutions benefited from sharing research methodologies and data analysis techniques, as well as dissemination of the research findings. The research teams also benefited from the vast experience of indigenous knowledge systems on WEF nexus practices by the participating communities and households. Participating communities and households benefited from the new knowledge on the linkages among the WEF resources which they use, as well as sharing indigenous knowledge systems among them.

Appendix 3: Journal article on literature review published in the IJFSA

HILL PUBLISHING

International Journal of Food Science and Agriculture, 2023, 7(3), 346-359
https://www.hillpublisher.com/journals/jsfa/
ISSN Online: 2578-3475
ISSN Print: 2578-3467

Integrating Water-Energy-Food Nexus Innovations and Practices into Policy, Governance and Institutional Frameworks for Sustainable Development in Vhembe District, Limpopo Province, South Africa: Literature Review

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How to cite this paper: Emmanuel Mwendera, K. D. Musetsho, T. Madzivhandila, R. Makungo, N. S. Mamphweli, K. A. Nephawe, T. Volenzo. (2023) Integrating Water-Energy-Food Nexus Innovations and Practices into Policy, Governance and Institutional Frameworks for Sustainable Development in Vhembe District, Limpopo Province, South Africa: Literature Review. *International Journal of Food Science and Agriculture*, 7(3), 346-359.
DOI: 10.26855/ijfsa.2023.09.003

Received: July 31, 2023
Accepted: August 28, 2023
Published: September 26, 2023

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Abstract

A review was conducted on the body of literature that covers areas such as global perspectives of water-energy-food (WEF) nexus, the need for WEF nexus solutions, WEF nexus interlink ages and frameworks, the WEF nexus research in South Africa, WEF nexus innovations and practices, policy and governance and institutional dimensions of WEF nexus and the application of WEF nexus solutions at the household and community levels. Literature searches were carried out in the indexed database Scopus©. Word clouds were used as indicators of search content summaries. Two searches on Scopus were carried out. The first search had search words of: ("Water-energy-food" OR "WEF" AND "South Africa" AND (Limit-To (Language, "English")), and it yielded 32 articles from 2003 to 2022. The second search had search words of: ("Water-energy-food" OR "WEF" OR "water policy" OR "water governance" AND "South Africa" AND (Limit-To (Language, "English")), and it yielded 260 articles from 1996 to 2022. The review findings showed that there are various methods and approaches for conducting research on the WEF nexus approach. These approaches provided the basis for developing the methodology for the current study. The literature review findings also highlighted the need to understand the existing and potential WEF nexus innovations and practices applied at the household and community levels and how existing policies and governance systems affect the use and management of WEF resources at these levels. Based on the literature review, it was decided that the ongoing research should focus on WEF nexus innovations and practices applied at the household and community levels, and on how existing policies, governance and institutional systems affect the use and management of WEF resources at these levels, in order to contribute to existing body of knowledge on WEF nexus.

Keywords

Water-energy-food, literature, review, innovation, policy, governance