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Operationalising the water-energy-food nexus through the theory of change

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ABSTRACT

The water-energy-food (WEF) nexus facilitates understanding of the intricate and dynamic interlinkages among the three resources. Its implementation can enhance resource securities and sustainable development. Despite its potential, full adoption of the approach has been hindered by a lack of actionable strategies to guide its practical application. This is attributed to (i) poor data (ii) lack of empirical evidence, (iii) inadequate analytical tools, and (iv) lack of clarity on applicable spatial scale. This study undertook a literature review, coupled with systemic analyses of a WEF nexus analytical model, whose outputs were used as a basis to develop a Theory of Change, an iterative outline for operationalising the approach in the context of southern Africa. The consultative and iterative Theory of Change culminated with the formulation of pathways to (i) overcome the barriers impeding WEF nexus operationalisation, (ii) mitigation of trade-offs while enhancing synergies towards attaining simultaneous resource securities, (iii) poverty alleviation and reduction of inequalities, and (iv) reconciling policy with implementation scale. The WEF nexus operationalisation outcomes are linked to Sustainable Development Goals 2 (zero hunger), 6 (clean water and sanitation), and 7 (affordable and clean energy), with synergies to SDGs 1 (no poverty), 5 (gender equality), 8 (decent work and economic growth), 12 (responsible consumption and production), 13 (climate action), 14 (life below water), and 15 (life on land). Operationalising the WEF nexus through an interactive process can inform sustainable pathways towards resource security, job and wealth creation, improved livelihoods and well-being, and regional integration.

1. Introduction

The projected African population growth to about two billion people by 2050 will further exert pressure on already depleted resources as demand exceeds supply [1]. Coupled with other multiple stressors, such as dependence on climate-sensitive rainfed agriculture, lack of resources to adapt, poor infrastructure, lack of institutional arrangements, and low adaptive capacity, there is increasing uncertainty as to the security and sustainability of essential natural resources in southern Africa and beyond [2–4]. Climate change projections indicate a reduction in the productivity of over 50% of agricultural land in southern Africa by 2050, and a reduction of between 10 and 30% in rainfall, a situation that threatens the livelihoods and well-being of over 60% of the population living in rural areas relying on natural systems [5–7]. The Intergovernmental Panel on Climate Change (IPCC) estimates that 350–600 million people in Africa will be at risk of increased water stress by 2050 due to rainfall variability [8]. Furthermore, the International Energy Agency (IEA) indicates that only 32% of southern Africa's population currently has access to electricity [9]. This shortfall could increase due to population growth and limited planning to improve energy access to most of the population [9]. The increasing demand for, and uneven

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List of abbreviations

AQUASTAT	FAO's Global Information System on Water and Agriculture
EU	European Union
FAOSTAT	Food and Agriculture Organisation Corporate Statistical Database
GWP	Global Water Partnership
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MCDM	Multi-criteria decision making
RSAP	Regional Strategic Action Plan
SADC	Southern Africa Development Community
SDGs	Sustainable Development Goals
SHEFS	Sustainable and Healthy Food Systems
SIWI	Stockholm International Water Institute
ToC	Theory of Change
UKZN	University of KwaZulu-Natal
WEF	Water-energy-food nexus
WEF-ToC	WEF nexus Theory of Change
WRC	Water Research Commission

distribution of these essential and interlinked natural resources (water, energy, and food) accelerates their depletion in southern Africa [10,11]. This has brought about calls for transformative, integrated, and systematic approaches to managing natural resources and improving social services delivery and planetary health [12].

The depletion and degradation of natural resources in southern Africa present the greatest threat to regional growth and achieving sustainable development by 2030 and the 2063 African Agenda [11]. The situation is exacerbated by the increasing intensity and frequency of extreme weather events like droughts, heatwaves, cyclones, and flooding and the prevalence of pests and diseases [13]. This has resulted in crop failure, destruction of infrastructure, and loss of human life, developments that threaten to reverse and derail economic gains made in the past [4,14]. Current sector-based institutional and governance arrangements are inadvertently fuelling the mismanagement of natural resources, at both national and regional scales [11]. Sectoral management of resources lacks coordination, dialogue, and collaboration, among relevant sectors, significantly affecting resource use efficiency, and the effectiveness of policies that address service delivery [13].

These bottlenecks need to be addressed through a transformative and integrated systems approach, such as the water-energy-food (WEF) nexus, balancing trade-offs, and synergies in resource management [7]. However, adopting and eventually operationalising the WEF nexus requires a paradigm shift from the current 'siloed' institutions and governance structures to those aligned to 'nexus thinking', in the public and private sectors [15]. As the nexus shifts from water-centric to multiple resource systems, it accounts for the integrated dynamics linking politics, resource security, environments, economies, and societies, which can be viewed as complex and adaptive systems [16,17]. This was noted well before its introduction in 2011 by the Stockholm International Water Institute (SIWI) at the World Economic Forum [16,17]. However, since 2011, the concept has emerged as a holistic and integrated resources management approach and a catalyst for sustainable development [18,19].

Given the shared nature of resources in southern Africa, operationalising the WEF nexus at the regional level can address the challenges related to water, energy, food insecurity, unemployment, and social imbalances [13,20]. The WEF nexus approach promotes long-term water, energy, food security and sustainability, and eventual preparedness for systemic shocks through scenario planning [6,21]. However, since its introduction in 2011 [19], the WEF nexus has been presented as a discourse tool or a conceptual framework without offering effective analytical tools or operationalisation strategies [22]. The WEF nexus came to the fore intended as a systemic approach that (i) indicates the performance of resource utilisation and planning, (ii) establishes quantitative relationships among interlinked resources, and (iii) indicates priority areas for intervention, aimed at establishing a balanced resource use and planning, and inclusive economic growth for sustainable development [7]. Thus, the approach is envisaged to catalyse climate change adaptation and resilience-building initiatives, improve human wellbeing, and steer up the attainment of Sustainable Development Goals (SDGs), particularly SDGs 2, 6, and 7 [6,11].

However, despite its potential, operationalising the WEF nexus remains elusive due to the inability of current models to move the theoretical model approach into a practical decision support tool. Critics of the approach have often based their arguments on the failure of the WEF nexus to offer practical solutions, and the lack of adaptable guiding frameworks [23]. Some even suggest that its operationalisation is far from being achieved [24]. The criticisms are compounded by the substantial literature portraying the approach only as a theoretical framework but lacking analytical tools [24,25]. The failure to address these key issues by existing models has been their main drawback, as they also either remain theoretical or maintain a 'siloed' approach to resource management [22,24]. An effective WEF nexus analytical model should assess the three sectors simultaneously and providing unified evidence on quantitative and qualitative relationships among the sectors and eliminating the sectoral approach in practice [7].

1.1. An overview of WEF nexus interventions in southern Africa

In southern Africa, the WEF nexus approach is anticipated to address issues related to water, energy, and food security in an environmentally and socially sustainable way to improve livelihoods, build resilience and enhance regional integration [13,26]. However, these targets have been elusive mainly due to habitual sector-based approaches in resource management, which inadvertently create an imbalance in resource allocation, resulting in scarcity and inequality in some areas [27]. Climate variability and change also exacerbate resource depletion, further compounding regional vulnerabilities [28]. The situation is worsened by the dependence on climate-sensitive sectors of agriculture and hydroelectric energy, which require abundant and consistent water supply [4]. Thus, operationalising the WEF nexus in southern Africa is envisaged to integrate strategies for adapting to the challenges of steep population growth, rapid urbanisation and increased consumer demands due to improved living standards, and climate change and variability [11]. Such integration would result in (i) savings from the costs that are caused by duplication of activities, (ii) increased efficiencies by collectively prioritising strategic activities, and (iii) a higher likelihood of success due to consideration of WEF nexus trade-offs and synergies. However, the approach's success hinges on governance and institutional transformations, aligning policies and strategies to nexus planning, which allows joint adoption by both the public and private sectors. Operationalising the WEF nexus at a regional scale in southern Africa provides opportunities to reduce vulnerabilities, inequalities, and poverty levels. It is a catalyst to achieving the 2030 global agenda on sustainable development [13]. However, such an endeavour requires regional countries to shift from the sovereignty mindset to one that realises the transboundary nature and uneven distribution of natural resources across the region and within some transboundary river basins, and to identify the potential synergies from collective planning and implementation across non-natural territorial boundaries [13,27].

The anticipated important role of the WEF nexus in sustainable development in southern Africa is evidenced by the increasing number of research projects and publications since 2013. The Southern Africa Development Community (SADC) has been spearheading WEF nexus research through the Global Water Partnership (GWP), and other stakeholders, since the *Sixth Multi-Stakeholder Water Dialogue* held in

Lusaka, Zambia in 2013 (www.sadc.int/news-events/news/6th-sadc-multi-stakeholder-water-dialogue-water-energy-food/). Furthermore, watercourse commissions, universities, and research institutions have been conducting WEF nexus research. Currently, the SADC Secretariat has produced the WEF Nexus Action Plan, through the Regional Strategic Action Plan (RSAP) on Integrated Water Resources Development and Management, that recognises the role of the nexus in adapting to the challenges faced by the region, as well as in optimising resource use [29]. The WEF Nexus Action Plan is a region-wide WEF nexus operational framework to support the attainment of regional goals and targets, including regional integration, poverty alleviation, and improved livelihoods and well-being. The Action Plan also recognises the role of the WEF nexus in achieving related SDGs, particularly Goals 2 (zero hunger), 6 (clean water and sanitation), 7 (affordable and clean energy), and 13 (climate action), 14 (life below water, and 15 (life on land).

A fundamental step towards operationalising the WEF nexus is transforming the concept from theory to practice and direct resource management in an integrated manner [7]. This requires stakeholder engagement at all levels of the public and private sectors (vertical), as well as across sectors (horizontal), as driven by enabling institutional and governance instruments [15,30]. Cross-sectoral coordination facilitates an effective nexus approach, permitting sound relationships among related institutions, allowing them to cooperate and work towards a common goal [28,31,32].

This study is based on the Southern African Development Community-European Union (SADC-EU) Nexus Dialogue Project that focused on analysing the transitions of the WEF nexus from theoretical research to practical actions and impacts in southern Africa. Since 2013, various platforms, science-policy dialogues, workshops, and symposia were organised to partner with various stakeholders to share research output on the WEF nexus [6,7,33–36]. Key challenges remain mainly in terms of driving a more practical evidence-based decision-making approach. Recently, decision support tools for the WEF nexus have been developed to establish contextualised quantitative relationships among the WEF sectors within the South African context [7]. Buoyed by this evidence and previous cross-sectoral resource management assessments, this study focuses on developing an operational framework to facilitate the envisioning of its implementation. The premise was to develop plausible pathways towards operationalising the WEF nexus through a dynamic and iterative Theory of Change (ToC) for informing policy and strategic decisions related to achieving socio-economic and environmental sustainability. The aim was to provide pathways towards operationalising the WEF nexus and how, through doing so, the region could achieve its vision of sustainable natural resources management, job, and wealth creation, WEF resources securities and regional integration, notwithstanding the existing challenges. Operationalising the WEF nexus is envisaged to facilitate achieving regional goals, and meet the targets set out in the African Union's Agenda 2063 and the SDGs.

2. Methods

2.1. Stakeholder engagement process

The main methodological approach used to derive the required results was a stakeholder engagement process which had various phases, where the first part included an overview of currently available WEF nexus analytical tools that evaluate synergies and trade-offs among the WEF resources. As an antecedent to the current work, the team developed a WEF nexus analytical model that integrates various indicators related to the security of WEF resources [7]. The tool was developed through the Analytic Hierarchy Process (AHP) in a multi-criteria decision-making (MCDM) process. The analytical model provided the required evidence to support the Science-Policy and Regional Dialogues [37,38]. Based on the developed analytical model and expert opinions obtained from a Water Research Commission (WRC)/University of KwaZulu-Natal (UKZN) think-tank, the team explored the transformational pathways required to turn the WEF nexus into a practical decision support tool in the context of southern Africa. The idea that was interrogated was: "Given the current evidence regarding the operational aspects of the WEF resource base, scaling, and data requirements, how can complexity be addressed to capture WEF collaboration and governance contexts that overcome the traditional technical and 'most-rational-solution' methods?''

The team has been involved in water research for the past decade focusing on sustainable food systems, agricultural water management, climate change adaptation, the WEF nexus, project management, adaptive biodiversity, and conservation management initiatives in southern African. The WRC/UKZN think-tanks and the expert discussions culminated in reaching sufficient consensus about which features are currently perceived as nexus transition gaps. Moreover, in the form of a World Café Discussion, a participatory exercise was conducted as a side event during the WRC Symposium in South Africa in September 2019. The aim was to gather the audience's opinions, which were invited as WEF stakeholders, regarding the challenges they perceive as barriers to the WEF nexus's successful operationalisation. Participants were asked to respond to the same question asked to the expert group. Altogether, 61 participants represented different sectors that included academia, policy, consultancy, and other public and private stakeholders. Participants provided prior informed consent according to the UKZN Human and Social Sciences Research Ethics Committee requirements. The lead authors, who are transdisciplinary research specialists in the WEF nexus, led the participatory exercise acting as both researchers and practitioners.

Following the World Café Discussion, the idea of the WEF nexus Theory of Change (WEF-ToC) was conceived and the process culminated in developing the building blocks that were perceived important in operationalising the concept. This resulted in integrating the expert opinion discussion with the stakeholders' outlook on the WEF nexus. Special emphasis was laid on questioning the long-term goal that was expected to be achieved when considering the WEF resource base's operational aspects, scaling, and data requirements. The interrogations addressed at each level of the ToC are given in Table 1.

The general conclusion from the consultative processes was that transitioning into the nexus implementation domain necessitates an understanding of complex realities. This is because emergent outcomes are likely to occur where partnerships and network governance, such as those involved in WEF security, are considered. Therefore, activities and specific objectives emerge through negotiation, developing, and using opportunities to generate emergent outcomes [39]. The conceptual meaning of 'outcomes' is inevitably linked to underlying assumptions and meanings which may not be evident to users of the term [40]. Therefore, it is essential to clarify a set of desirable outcomes and how the complex intervention aims to create impact pathways that drive the systemic change and generate the desired outcomes.

Table 1
Systemic questioning for WEF nexus operationalisation.

Level of Change	Exploratory questions to theorise pathways for nexus transitioning
Impact	How can complexity be addressed to capture WEF collaboration contexts that overcome the traditional technical and 'most-rational-solution' methods?
Outcomes	What is the status of WEF resources in southern Africa?
Outputs	How can the WEF nexus be objectively operationalised?
Activities	What analytical model(s) is most suitable for WEF nexus analysis? At what scale should the WEF nexus be applied?
Inputs	What are the data requirements and availability at each scale of application?

2.2. The logic for choosing the Theory of Change

A ToC is a model that addresses pathways of change and how those changes are expected to occur (*ex-ante* case) or how change has occurred (*ex-post* case) [41]. As such, a ToC has various uses that include designing, managing, and accessing interventions [41]. The ToC evolves from theory-driven evaluation and seeks to move beyond a simplistic input-output notion of intervention evaluation. In the context of the WEF nexus, it requires that the WRC/UKZN think-tank designers explicitly state how they expected the implementation practice to work, thereby making their implicit assumptions explicit. This created a better understanding of what is being implemented and why, making clear the connections between a given intervention and its outcomes. These were interrogated, assessed, and revised systematically as it was being implemented [41]. Thus, the adopted argument was that transitioning from water-centric research to the multicentric WEF nexus implies implementing even more interventions with multiple components and agencies, multiple simultaneous causal strands, and/or multiple alternative causal strands with complex aspects [39].

The ToC framework for operationalising the WEF nexus described in this study is not an end, but it sets the pace to recognise systemic insights and adaptive management across the nexus. Ideally, this recognition should not only be at the decision-making level but should resonate across sectors, jurisdictions, and research-practice interface. Alternative methods to planning research interventions include the logical framework analysis, which emphasises a linear input-outcome standpoint without the opportunities for developing and nurturing systemic insights in the light of complex collaborative realities [42]. As much as a ToC facilitates long-term strategic planning and monitoring of interventions, support reflection, and learning about change processes to integrate the findings, the development of meta-capabilities is also discussed as a set of levers required to catalyse the WEF nexus operationalisation [43].

2.3. Components for WEF nexus transition thinking

The methodological outline (Fig. 1) illustrates the thematic areas that were considered by the expert groups and are based on the context of the WEF nexus framework for southern Africa and the regional goals, namely, to achieve (i) simultaneous and long-term water, energy, and food security, and sustainability, (ii) job and wealth creation, and (iii) regional integration and inclusive economic development [13]. The WEF nexus approach emphasises integrated resource management, specifically for the interlinked water, energy, and food resources. As the approach aims to address the limitations associated with sector-based planning, it is envisaged to reduce poverty and vulnerability through inclusive and equitable resource planning, development, and distribution. Thus, the Venn diagram (Fig. 1) addresses sustainable WEF nexus adaptation targets, including poverty and vulnerability reduction, achieved by managing resources holistically.

Overcoming the barriers associated with the WEF nexus operationalisation (the first block of the matrix in Fig. 1) is key to achieving the WEF nexus sustainability targets given in the Venn diagram. The barriers that must be overcome include complex collaboration between interlinked sectors, divergent sectoral institutional frameworks and interests, poor governance frameworks, and lack of motivation to cooperate with different stakeholders from different disciplines and government levels. Other barriers to WEF nexus implementation include uncertainty and anxiety, which are brought about by the fear of the unknown due to change from the norm to novel ways of doing things.

The development of WEF nexus analytical tools (the second block of the matrix, in a clockwise direction in Fig. 1), offers opportunities to provide a synopsis of the quantitative and qualitative relationship in the use, planning, and management of the three resources. Such a synopsis in the relationship of resources with different measurement units is established, for example, through multi-criteria decision making (MCDM), which is key to the analytical tool, and represented using a spider diagram [7]. The evidence provided by analytical tools is useful for identifying areas for intervention and informing decisions in resource management that ought to be applied through transformative methods (nexus planning, scenario planning, sustainable food systems and circular economy), as shown in the matrix's third block (see Fig. 1). The WEF nexus analytical tool's capability to identify areas for immediate intervention was the missing piece in operationalising the approach [7]. However, this is dependent on the application scale (the fourth block of the matrix in Fig. 1) and data availability for that scale.

Having unpacked most of the expert-based methodological outline's essential building blocks, the remaining gap yet to be explored is the implementation strategy to operationalise the WEF nexus (the centrepiece block of the matrix with the question mark in Fig. 1). As the process demands a major shift from the status quo, emphasis should be placed on nurturing stakeholder engagement and commitment. The overarching goal is to create a platform to establish WEF nexus governance and institutional frameworks that drive towards desired outcomes, such as resource security, equitable and sustainable development, and a healthy environment (Fig. 1).

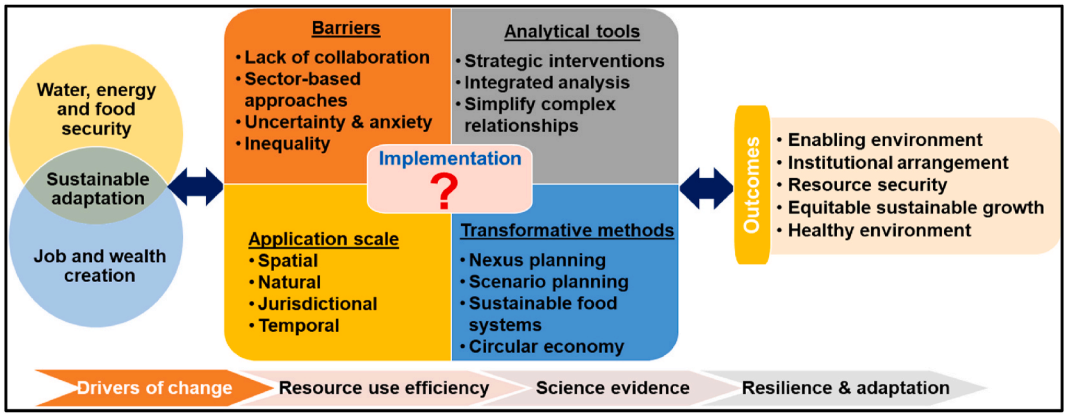

Fig. 1. A stepwise WEF nexus methodological outline illustrating the systemic processes and adaptation targets and action fields towards WEF nexus operationalisation. Sustainable adaptation has a dual purpose acting as the driver and impact derived from systemic change. Resource use efficiency backed by scientific evidence ought to address the four contextual governance gaps identified. These could either create or compound WEF security challenges namely (i) complex collaboration, (ii) types of analytical tools to generate evidence, (iii) determinants of application scale and, (iv) transformational lenses to achieve large-scale systemic change. Finally, outcomes to be derived from an optimised nexus transitioning ought to ensure resilience through adaptive management.

3. Results and discussion

The outcomes of the stakeholder engagements resulted from a specified chronological order: first, expert opinions were sought through dialogues to discuss the components that would shape the WEF nexus' strategic transition and enactment. The second step comprised a stakeholder engagement workshop to gather feedback from participants in a World Café setting. Thirdly, the elements discussed by the stakeholders were combined, within a ToC, as preconditions to envision the multiple impact pathways required to achieve the overarching nexus transition outcomes. Finally, because the WEF nexus has been deployed to connect water, energy, food, and climate to the global economy in terms of complex systems, levers to achieve transformational capabilities were also discussed. The outcomes of these four steps form the results section where an interpretation and discussion on the significance of the outcomes is also given.

3.1. The WEF nexus Theory of Change (WEF-ToC)

3.1.1. Formulating the problem statement to accentuate contextual pathways to reach outcomes

The World Café Discussion culminated in the formulation of the WEF-ToC (Fig. 2). The process refined the WEF nexus operationalisation planning, starting from the design stage to enhance locally led stakeholder buy-in and create a sense of ownership. The design stage outlines clear activities that need to be implemented to achieve the envisioned desired human outcomes. The ToC also identified the contextual factors that are envisaged to influence those outcomes, factors that also influence the adoption of the WEF nexus by decision-makers. Participants highlighted the importance and relevance of context regarding societal needs, risks, and current capabilities strength. This was deemed essential to articulate the overarching vision to improve livelihoods and ecosystem services. The synergies needed to achieve the human outcomes were based on the targets of the SDGs. The discussion emphasised the need for an adaptive enabling environment to harmonise policies considering WEF securitisation challenges. These conditions ought to improve programme outcomes assessment based on interdisciplinary and cross-sectoral evaluation and reflection. Participants foresee challenges in terms of application scale and data requirements at the implementation phase, which can essentially be addressed by generating relevant contextual evidence.

The building blocks in Fig. 2 explain the implementation and evaluation process for operationalising the WEF nexus in southern Africa, but it can be adopted anywhere at the national or local levels. The process is necessary for providing feedback and a knowledge base about the need and basis for WEF nexus operationalisation. Articulating the ToC at the outset and engaging stakeholders minimised the challenges associated with causal attribution of impact. They highlighted the activities that lead to short- or long-term outcomes and unveil the circumstantial conditions that may affect and direct outcomes [32]. Therefore, it strengthened the evidence for subsequent implementation of the approach. Thus, the analytical model saved as a lens for policy and decision-making to formulate coherent policies build around nexus planning.

Effective and influential governance structures have to be leveraged at strategic points in the context of the WEF nexus within an organisation [44]. The building blocks in the WEF-ToC indicate complex interactive structures held together by a balance of incentives to leverage the

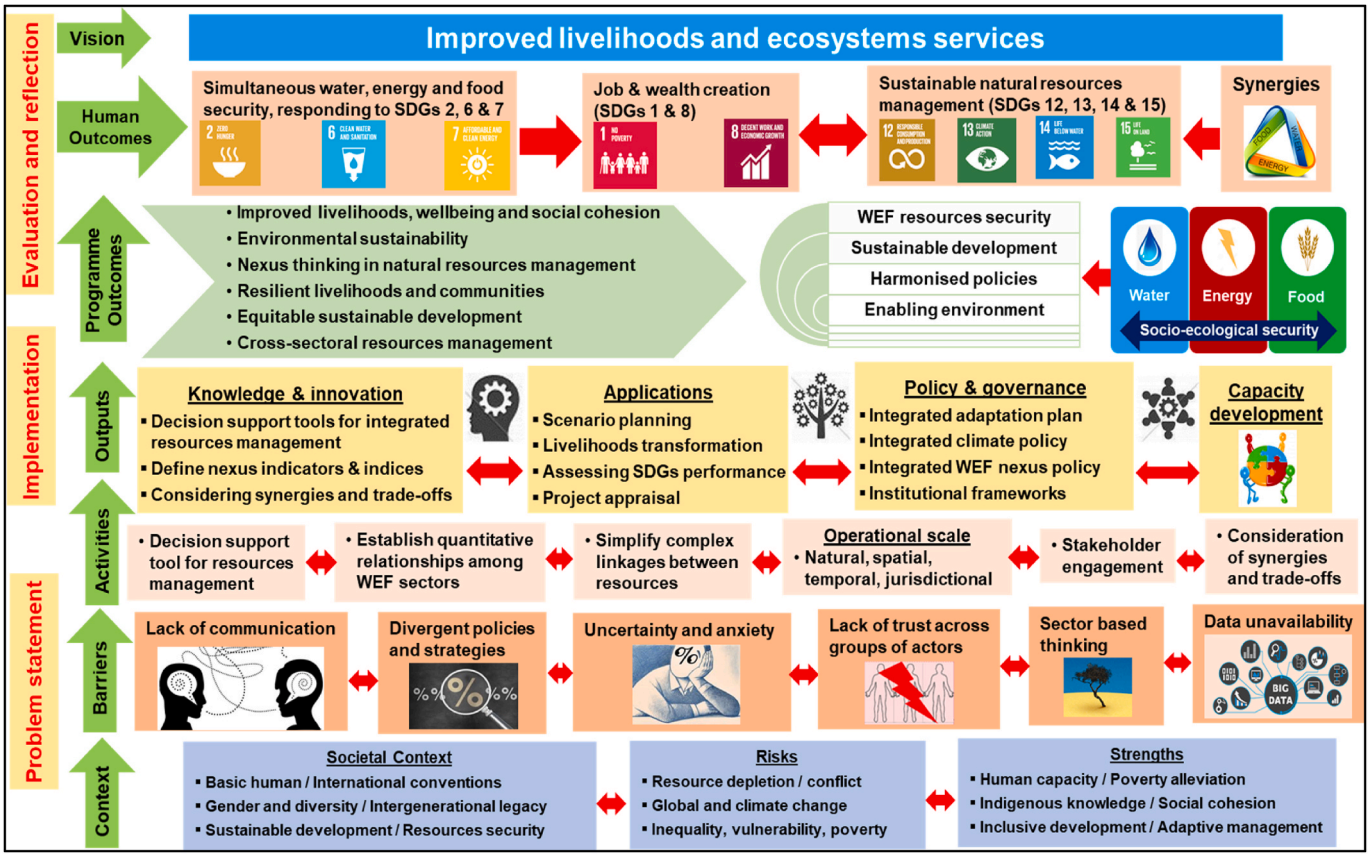

Fig. 2. The Theory of Change for complex interventions to operationalise the WEF nexus in the context of southern Africa. The problem statement defines the context of the WEF nexus and perceived barriers to implementation. With a view to balance trade-offs and positively reinforce synergies in the implementation phase, sufficient consensus has been reached to promote the normalisation of complex collaboration process through adaptive stakeholder engagement and methods to assess WEF nexus interaction.

buy-in from stakeholders, namely researchers, practitioners, and government agencies, to maximise the contributions received from them.

3.1.2. Application scale for the model

While the nexus concept is envisaged to address global challenges associated with climate change, rapid urbanisation, limited resource base, growing population, among others, it is at the local scale (household and community), and natural scale (catchment) where nexus takes place, and where adaptation and resilience-building occur at varying levels, depending on capabilities and capacities [24,45]. Local and natural spatial scales are closely linked to jurisdictional scale (political units like cities, municipalities, or provinces), which are responsible for formulating and implementing policy and governance that affect households and communities [46,47]. The fourth scale important in nexus analysis is the temporal scale, which is especially vital in scenario planning for interpreting future climate change situations, resource availability, or population projections at different time intervals [48]. The applicability of the WEF nexus at each of these four scales is dependent on data availability. Each spatial scale has its own dynamics when it comes to data availability for the indicators. For example, the water indicator on the "*proportion of crops produced per unit of water used*" may not be appropriate in an urbanised municipality or at the household scale, but applicable at national and regional scales (Table 2). Although the model could still be applicable, there will be a need to adjust or adapt the indicators to suit each spatial scale. Moreover, the WEF nexus indicators should always be assessed within the broader indicators to allow for integration and scaling at different spatial scales. This flexibility to incorporate other indicators is an important component of the integrative WEF nexus analytical model to be extrapolated to different levels or different situations [7].

3.2. Data requirements and availability for WEF nexus application

While implementing the WEF nexus as a management and governance tool has gathered momentum worldwide, one main challenge relates to data availability and heterogeneity needed to provide insights based on a top-down (national-local) approach [25]. The variation in WEF nexus applicability scales brings about a host of other challenges, which include data disparity, mismatch, and plurality, as there are varied methods of data collection and storage [25]. Data availability allows stakeholders to take stock of economic and environmental resources through the WEF nexus analytical model, providing a detailed overview of natural resources stocks and flows through a spider graph, portraying resource use and management [7]. However, the heterogeneous nature of data at different WEF nexus spatial scales, and the distinct methods of data collection and archiving, and different data quality and standards present some challenges when applying the analytical model in a standardised manner. Coupled with appropriate nexus analytical models like the one developed by Nhamo et al. [7], data availability plays an important role in evaluating trade-offs and synergies to avoid conflicts and risk reduction [49]. The essence of the WEF nexus is its recognition of the WEF resources' interlinked nature, and its capability to promote synergies and reduce trade-offs, which are vital aspects of sustainable development. Thus, data requirements for the WEF nexus vary according to the issues being tackled, and its availability at every scale is the major challenge [7].

The availability of data simplifies WEF nexus complexity by applying the WEF nexus analytical model developed by Nhamo et al. [7], enabling decision-makers to make evidence-based, appropriate, and proactive intervention strategies, taking into account the diverse and multiple impacts these responses may have across sectors and over time [7]. Data availability is, therefore, key in operationalising the WEF nexus. Data are generally available at national or regional levels in accessible databases such as FAOSTAT, AQUASTAT, and the World Bank Indicators. At the local municipal level, WEF data are generally recorded through smart-meter technologies installed at household levels, thus, data can also be available at the household level for specific indicators, except that challenges may arise where this is not practised. The other challenge is standardising the WEF nexus analytical model as some indicators may not be valid at all scales. However, where data are not readily available, existing, and planned Earth Observation systems have proven to be important data sources [50,51]. The success of sustainable development hinges on the availability of reliable data at all levels and human understanding and evidence-based appropriate planning, and expert opinion.

Table 2 provides a synopsis of data availability at different scales in southern Africa for each of the considered WEF nexus sustainability indicators according to the set criteria. WEF nexus data are generally available at regional and national scales, but there are disparities at the catchment, municipal, and household scales. For example, some of the indicators may have to be adjusted to suit household dynamics at the household level.

Interestingly, data could be readily available at the household and municipal levels but becomes scarce at the basin level. This is possible in southern African as data is generally available in urban areas where water and electricity usage are metred, and food consumption styles are known. Yet, the same data could be unavailable at the basin level as the shared transboundary river basins include rural areas with no proper data monitoring mechanisms [7,52]. As many countries share the basins, the data collection methods differ from country to country, making the data collection highly heterogeneous [52].

Table 2
Data availability at various spatial scales for WEF nexus application in southern Africa.

Indicator	Spatial scale				
	Regional	National	Basin	Municipal	Household
Proportion of available freshwater resources per capita					
Proportion of crops produced per unit of water used					
Proportion of the population with access to electricity					
Energy intensity measured in terms of primary energy and GDP					
Prevalence of moderate or severe food insecurity in the population					
Proportion of sustainable agricultural production per unit area					

Key	Readily available	Scarcely available	Not available

3.3. WEF nexus implementation through transformational meta-capabilities

Successful WEF nexus operationalisation requires robust structures that promote stakeholder buy-in and evidence-based instruments and application tools to move the transformational process. The concept acknowledges that transformation is dependent on both behavioural and voluntary processes that drive resilience from multiple scales and diverse sources. Allowing the monitoring and evaluation of change in both the private and public sectors [53]. It is, therefore, a catalyst for resource use efficiency and sustainable development. Such a transformative instrument enhances the preparedness and readiness of society against shocks in the socio-ecological systems. It addresses the dynamics and developments of complex social-ecological interactions towards resilience and adaptation [54]. The processes facilitate data collection, ensure stakeholder engagement, and monitors and evaluate the progress towards intended goals over time as they are iterative. The success of these processes is enhanced through ongoing stakeholder engagements [53].

Effective and influential governance structures have to be leveraged at strategic points in the context of the WEF nexus within an organisation [44]. The building blocks in the WEF-ToC indicate complex interactive structures held together by a balance of incentives to leverage the buy-in from stakeholders, namely researchers, practitioners, and government agencies, to maximise the contributions received from them. A meta-capabilities perspective is used to illustrate the influential levers that harness the competencies for nexus operationalisation (Fig. 3). Lever (A) refers to building effectiveness through evidence. This has occurred mainly through the positive reinforcing outputs of nexus thinking alongside niche experiments and innovations in the WEF systems. The development of WEF nexus analytical tools has paved the way to operationalise the approach effectively. The focus on improving effectiveness occurs within the academia and research context, as this is where the building blocks for evidence are produced. Lever (B) considers the rigour of the capacity-building process at (A) within different contextual requirements, such as funding and scales, to determine the potential to improve effectiveness strategically (Fig. 3).

Lever (C) harnesses both the capacity and the capabilities to prioritise a discourse to oversee the governance and operationalisation of the WEF nexus. The goal is to generate a policy framework to delineate action. Barriers identified in the WEF-ToC were considered as susceptible to constrain nexus operationalisation. Lever (D), therefore, mediates the effects of change, both in the environment and internal to the sub-systems research-academia, policy, and governance agencies. It consists of routines, knowledge, and technology that perform organisational functions. Thus, it addresses extrinsic barriers to effective uptake of new knowledge and intrinsic barriers preventing cohesive and coherent dialogues and consensus. Lever (E) scales the readiness of the WEF nexus system for polycentric and transformative change. The governance mechanisms serve a functional role within the converged system to enable activities that explore the environment (for cascading opportunities) and the WEF nexus's internal possibilities for developing new capabilities. Lever (F) renews competencies and reconfigures its capabilities to achieve unity with changing environmental contexts. Innovation, strategic alliances, and mergers and acquisitions are some of the means to achieve this meta-capability. Such dynamic capabilities form the mechanisms of recombination (adaptability) and change. Organisational capabilities and dynamic capabilities are considered to be complementary. Together, the levers make up the dynamic mechanisms of nexus operationalisation.

4. Recommendations and way forward

To achieve the vision of improved livelihoods and ecosystem services and associated human outcomes, an operational WEF nexus approach needs to be integrated with other transformative approaches [7,34], these include:

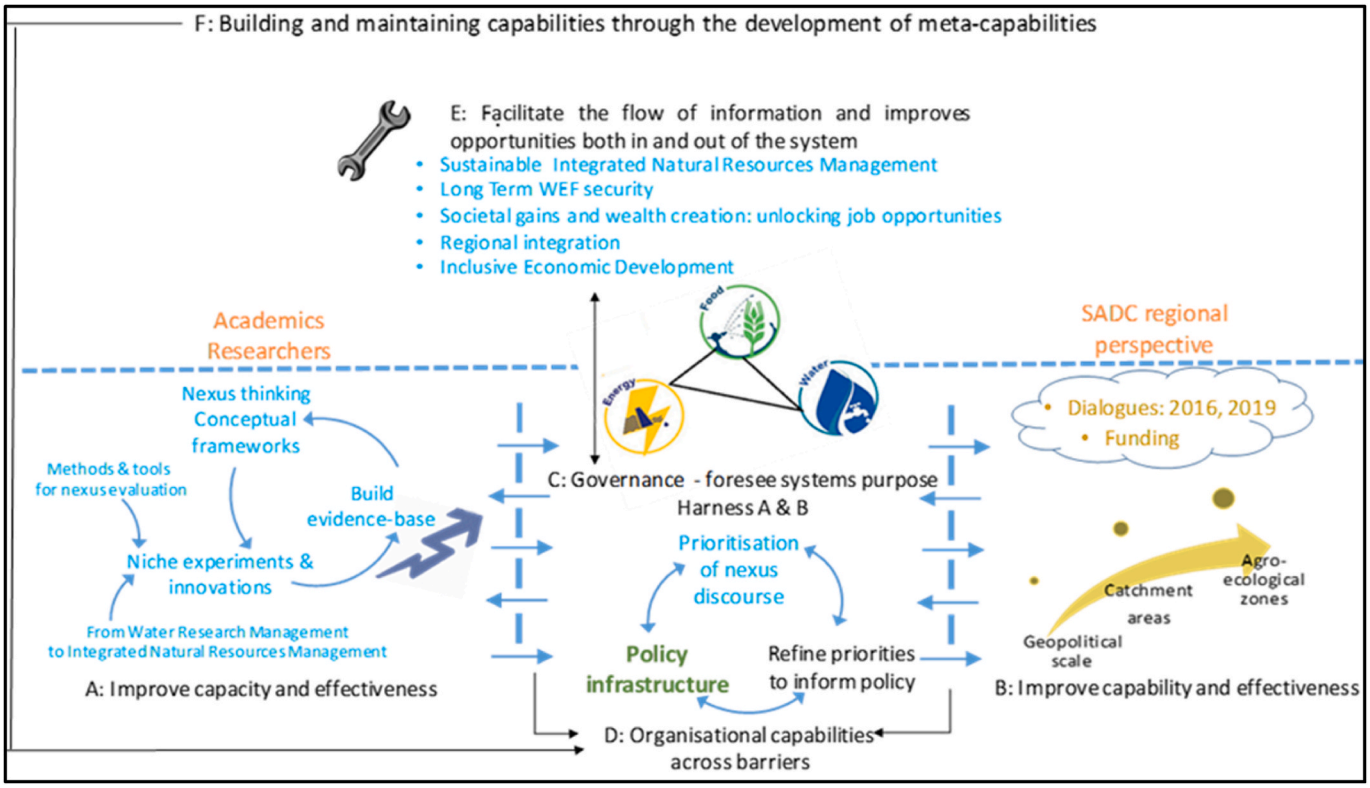

Fig. 3. Levers to catalyse WEF nexus operationalisation: a meta-capabilities perspective. Levers A to F represent the essential mechanisms that enhance WEF nexus transformational capabilities in achieving impact and regional goals.

1. **Scenario planning:** Scenario development supports policy and decision-making to formulate coherent strategies by developing alternatives and response options in climate change adaptation, other than models full of uncertainties [55]. These attributes establish linkages with the WEF nexus, as the nexus identifies priority areas for intervention, guiding the scenario planning process [56]. Unlike predictive models, scenarios provide multiple alternatives through stakeholder-led discussions and, therefore, minimise uncertainty. Thus, the WEF nexus analytical framework is a "fitting approach" for scenario development, as it provides strategic options by indicating whether intervention on any resource is sustainable or not and how the intervention affects the other sectors, providing options to mitigate trade-offs [57].
2. **Rural livelihoods transformation**: Societal megatrends such as increasing population growth, conflict and migration, economic growth, international trade, rapid urbanisation, diversifying diets, cultural and technological changes, as well as climate variability and change, continue exerting pressure on already depleted natural resources, threatening sustainability [58]. These challenges have widened the rural-urban inequalities, particularly in developing countries where rural communities rely on natural systems for livelihoods [59]. As economies grow, it is critical to ensure a vibrant rural economy that includes robust agricultural productivity, rural non-farm jobs, and access to markets and trade [60]. The WEF nexus is a decision support tool that ensures integrated resource utilisation and management and inclusive development, ensuring that rural areas are not neglected and central to economic, social, and environmental developmental plans [6,13].
3. **SDGs progress assessment**: As progress towards the SDGs is assessed through quantifiable indicators that track measurable targets, the WEF nexus contributes to the monitoring and evaluating progress towards the 2030 global agenda; WEF nexus indicators build on and compliment SDG indicators [7,61]. The WEF nexus analytical model assesses, monitors, and tracks resource utilisation and performance over time using some of the same SDG indicators. As a cross-sectoral approach, the WEF nexus integrates indicators across sectors and elucidates how best resources can be allocated between competing needs, thus, making the implementation of SDGs more efficient and cost-effective [21,62].
4. **Project appraisal**: The WEF nexus analytical framework is designed to systematically integrate and streamline the human understanding of resource utilisation and management. It, therefore, becomes an important tool for project planning and appraisal at all levels of the project cycle as it manages trade-offs and synergies. Thus, it is an important tool for project design and evaluation, for complex projects involving various expertise. The WEF nexus analytical framework enables project leaders and funders to quantify the linkages among WEF nexus components, identifies critical links and leverage the results to improve project design and implementation [23].
5. **Circular economy planning**: A circular economy is characterised by low energy consumption, low emission of pollutants, and high efficiency in resource use; it is restorative and regenerative, ensuring resource security [63]. These attributes provide the linkages with the WEF nexus as both are concerned with resource use efficiency and security through integrated planning and management [64]. Thus, the WEF is a catalyst for climate action and adaptation through informed and transformational decisions like the circular economy. A WEF nexus approach offers sustainable pathways to support the transition toward a circular economy by considering synergies and trade-offs coupled with optimising resource use efficiencies. In southern Africa, both the circular economy and the WEF nexus promote resource security and economic growth by creating employment opportunities, sustainable resource management, and reducing environmental pressures.
6. **Sustainable food systems:** A food system is composed of subsystems, value, and supply chains such as farm production, food processing, storage, and waste management. It is linked to other important systems such as energy, trade, and health systems [65]. The concepts of sustainable food systems and the WEF nexus are concerned with ensuring food and nutritional security and maintaining a sustainable economic, social, and environmental base that continues to meet the needs of the present and future generations [66]. To meet the growing demand for food (and bioenergy) and meet SDG 2 (zero hunger), agricultural production must nearly double by 2050 [18]. There are various approaches to this, with recent evidence suggesting sustainable intensification as the most ideal [67,68]. However, even then, sustainable intensification only provides a framework that needs to be supported by other cross-cutting approaches and collaboration to bring about the desired food system transformations.

Basing on the challenges facing southern Africa, the WEF nexus provides the pathway towards effective solutions to regional challenges that include: (i) the risks brought about by climate variability and change, (ii) increased land degradation, (iii) rural-to-urban migration, (iv) accelerated population increases, among others. Although the nexus approach will not solve all the problems related to humanity and natural resource, this is the starting point towards sustainability and resource use efficiency. Relevant governance and institutional structures are required to facilitate compliance at all scales and levels, from implementation at local communities to regional perspectives and integrated strategies. Governance structures ensure the coherence of developmental plans across national and provincial or subnational scales, and, importantly, communicating progress clearly across space and over time. This is essential for achieving sustainability by 2030. The proposed WEF nexus roadmap to operationalise the WEF nexus should be used within the transdisciplinary and interdisciplinary lens to encourage inputs and participation of various players.

Of note is the scalability and flexibility of the developed framework to operationalise the WEF nexus in other areas and at any spatial scale. Although the developed WEF-ToC is specific for southern Africa, the approach can be replicated in other regions using context-specific goals and challenges. These attributes, coupled with their iterative and interactive nature, permits the approach to be applicable at any spatial scale, particularly considering that challenges and priorities differ across spatial scales and context.

It is imperative to note that the approach does not intend to create a mega "Nexus Ministry", but rather build a strong and binding coordination mechanism that facilitates nexus policy dialogues, where key stakeholders can better identify and prioritise solutions together from an overall nexus perspective. With the available evidence from science, such dialogues allow line departments to priorities optimal projects that give the overall trade-off solutions for all sectors. Thus, effective collaboration is at the centre of WEF Nexus. The complexity of the WEF nexus requires stakeholder engagement from the onset as it is a change from the norm, and the prospects of facing opposition and resistance could be high. Engaging key stakeholders from the onset enhances the operationalisation framework's quality, acceptance, and legitimacy, improving the chance of informing decision-making. Raising awareness and creating a platform of stakeholder buy-in is a fundamental pathway through which the proposed changes could be adopted, particularly through concrete and viable projects at various scales. Importantly, transparency and ongoing communication are crucial to retaining participation and influence from the range of stakeholders.

5. Conclusions

The WEF nexus has developed into an important transformative and integrated approach for guiding other contemporary transformative systems, such as sustainable food systems, circular economy, scenario planning, SDGs progress assessment, and livelihoods transformation. It has become a decision support tool that provides evidence in complex

sustainability issues. This development has facilitated the WEF nexus transitioning from a conceptual and discourse tool into a fully-fledged operational decision support framework. Buoyed by this scientific evidence, this study developed a transitional strategic framework through the ToC, to move the approach from a theoretical tool into a practical and operational one. The essence of the operational framework is to develop a platform for cross-sectoral dialogues and institutions where key stakeholders can better identify and prioritise solutions together from an overall nexus perspective. Such cross-sectoral dialogues benefit from designing cost-effective policies that set multiple objectives, targeting several resources across sectors. This facilitates transitioning to alternative energy sources that positively influence water and food availability and accessibility, and vice-versa. Such initiatives promote technological innovations that enhance nexus planning, allowing identifying new options such as the circular economy and sustainable food systems that better explore the interlinkages among the WEF resources. Importantly, the ToC should be a living and dynamic framework, with opportunities for assessment, evaluation, reflection for continual improvement, and ongoing recruitment of additional stakeholders. These innovative approaches provide pathways towards sustainability and desired policy outcomes. The WEF nexus is a lens for long-term benefits through integrated and coordinated regional cooperation on existing and planned developmental projects. It is a platform for regional cooperation that provides opportunities for inclusive economic growth, job creation, and sustainable development.

Credit author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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