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Implementation of water energy food-health nexus in a climate constrained world: a review for South Africa

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In recent years, the Water-Energy-Food (WEF) nexus has gained significant attention in global research. Spatial inequality in water-energy-food security (WEF) and its impact on public health and how this is affected by climate change remains a grand adaptation challenge. South Africa is extremely vulnerable and exposed to the impacts of climate change due to its socio-economic and environmental context. While alternative nexus types have garnered interest, this paper pioneers an extension of the conventional WEF framework to encompass health, giving rise to the Water-Energy-Food-Health (WEF-H) nexus. Despite a plethora of WEF nexus studies focused on South Africa, a substantial knowledge gap persists due to the lack of a comprehensive overview of the enablers and barriers to realizing the WEF-H nexus. South Africa boasts diverse policies related to water, energy, food, and health; however, their alignment remains an ongoing challenge. This study seeks to bridge this critical gap by conducting an exhaustive review of existing literature. Its primary aim is to delve into the intricate mechanisms that either facilitate or impede the actualization of the WEF-H nexus in South Africa. By synthesizing insights from a wide array of literature sources, this research strives to illuminate the challenges and opportunities stemming from the integration of health considerations into the established WEF nexus framework. This exploration holds immense significance, not only for unraveling the multifaceted interactions between these pivotal sectors but also for guiding policy development and decision-making processes in South Africa towards a more holistic and sustainable approach to resource management.

KEYWORDS

WEF-H nexus, South Africa, enablers, barriers, policy alignment, sustainability

1 Introduction

Despite three decades of democracy, South Africa still struggles with the legacy of apartheid, including extreme inequality across racial and regional lines (Klug, 2021), widening gulfs between the rich and poor (Naidoo, 2005; Sibanda and Batisai, 2021) compounded with increased frequency of climate-induced hazards. The 1994 transition to majority rule in South Africa aimed to reduce socio-economic inequality, expand basic services, and embrace human rights principles as the foundation of constitutional solutions (Klug, 2021). Access to water, food, health, and energy services are basic human rights, but the struggle for these rights continues to echo the popular struggles of the apartheid era. The South African government is committed to eliminating poverty and reducing inequality by 2030, as set out in its key national policy documents, e.g., National Development Plan 2030 (NPC, 2011) and National Climate Change Response Policy (NCCRP) (DEA, 2011) as well as the international agenda for Sustainable Development Goals (SDGs) to which the government has subscribed. Despite the government's valiant efforts, many South Africans continue to face socio-economic challenges and the ramifications of climate change (Naidoo, 2005; Sibanda and Batisai, 2021). This reality is particularly pronounced among the country's black African population.

Like many developing countries, South Africa faces the challenge of balancing economic growth with environmental sustainability, what Simpson coined "reconciling growth with planetary boundaries" (Simpson and Jewitt, 2019). This means developing the economy in a way that is equitable, inclusive, and does not irreversibly damage renewable resources or fail to realize the full potential of non-renewable resources. However, South Africa's political economy has tended to prioritise an economic approach that transfers problems to a wide range of sectors. For example, mining rights often trump conservation of strategic water resource areas, agriculture lands and even human health considerations. As a result, tensions are growing between the increasing demand for, and use of natural resources (e.g., water, land, and energy) to support development and the availability and quality of those resources.

Coupled with its developmental challenges, the country is also water-stressed, with climate change (Nhamo et al., 2020) further compounding existing socio-economic challenges. Escalating food prices (Simpson and Jewitt, 2019) are leaving a large portion of the population highly food insecure, unable to meet their basic nutritional needs. Even more urgent and complex is the issue of the ailing energy system. Eskom, the national power utility has failed to meet the energy demand resulting in frequent power outages (Baker and Phillips, 2019; International Energy Agency, 2022) and increased rationing of the available energy (Lawrence, 2020).

South Africa has many policies related to water, food, and energy, which aim to make these sectors more sustainable. However, many stakeholders are increasingly recognizing the importance of managing the complex interactions between water, energy and food (WEF). The WEF nexus, an approach that considers these three sectors together, has been suggested as a governance solution to complex resource management challenges (Srigiri and Dombrowsky, 2022). This paper examines the implementation of the WEF-H nexus in a country case study,

with a focus on the key bottlenecks and enablers. The paper acknowledges that more than a decade after the introduction of the WEF Nexus as a governance (Keskinen et al., 2016), analytical (Nhamo et al., 2020) and ideological tool, the transition from "nexus thinking" to "nexus doing" remains essential to foster appropriate policy development, effective decision-making and practical implementation, in the context of water, energy, food, and health interlinkages.

The paper explores developments in the WEF-H nexus through an extensive literature review, unpacking its complexity and challenges within the South African context, and examining the key ingredients for successful implementation.

2 Understanding the nexus concept

The term "nexus" is central to the WEF-H Nexus, and it refers to a polycentric approach to problem solving (Srigiri and Dombrowsky, 2022). As such, the nexus concept is a useful framework (Keskinen et al., 2016) for action that brings together multiple actors and institutions at different levels of governance to address complex challenges. It is both an analytical tool and a discourse centred on the theory of polycentricity (Thiel, 2016) and polycentric governance (Ostrom, 2010) which means that power and decision-making are distributed across multiple centres.

In simpler terms, a nexus approach is a systems-based way of thinking about complex problems by considering how different sectors are connected and how decisions made in one sector can impact on others. This may be especially useful for identifying the inter-relatedness and interdependencies between sectors when making decisions about projects, strategies, policies and investment options in complex socio-environmental systems (DeLaurentis and Callaway, 2004). It aims to integrate research, management and governance across sectors and scales. The nexus approach assumes that there are biophysical and environmental limits to the degree to which resources can be exploited or pollutants can be absorbed, and that exceeding these limits will have potentially catastrophic impacts, either now or in the future.

Moreover, it is understood that there are complex feedbacks within and between sectors (Mutanga et al., 2016), often resulting in non-linear responses, and tipping points beyond which systems cannot easily recover (Cabrera et al., 2008). The nexus approach allows for a more holistic understanding of (un-)intended consequences of policies, technologies and practices whilst highlighting areas of opportunity for further exploration (Trist, 1981; Mutanga et al., 2016). It aims to enhance resource-use efficiency (resource-use getting more from less) and political cohesion by reducing resource trade-offs and increasing synergies. The nexus concept needs to be interdisciplinary and transdisciplinary, accepting a plurality of views (Geels, 2004). It is also participatory, requiring stakeholders to engage with researchers in jointly deriving potential solutions. Given the above dimensions, resource-use remains clear that no single definition can be used to define nexus and its applications, it remains an evolving concept. What is clear though is that it forms the basis within which the WEF nexus is defined and understood.

3 The water-energy-food-health (WEF-H) nexus approach

The Water-Energy-Food-Health (WEF-H) Nexus is a complex concept with no single agreed-upon definition or framework. It is often used to describe the interconnectedness of these four sectors, and how challenges in one sector can have cascading impacts on the others (Rasul and Sharma, 2016). The number of sectors included in the Nexus can vary, depending on the discipline or perspective and can sometimes add additional lenses such as livelihoods, ecosystems, and climate change (Keskinen et al., 2016). For example, those in the water sector may refer to the Nexus as WEF, while those in the energy sector may refer to it as EWF. The agriculture sector may define it as FEW, and the health sector may add the 'H' (Nhamo et al., 2020). This lack of common understanding can make it difficult to collaborate and develop effective policies and solutions.

Despite the lack of consensus on a definition, the WEF-H Nexus is a useful concept for understanding the complex challenges facing our world. It can be used as an analytical tool, a conceptual framework, or a discourse (Keskinen et al., 2016). Instead of passively acknowledging the existence of the WEF-H nexus, this paper argues that it is a critical driver of resilience in both our economy and society. Recognizing its interconnectedness demands proactive measures – not just awareness, but concrete policies and actions. By effectively managing this complex system, we can harness its synergies and mitigate challenges, ensuring the WEF-H nexus becomes a potent force for resilience in the face of interconnected water, energy, food, and health concerns.

Nexus studies equip us with the knowledge and tools to tackle complex challenges head-on. By delving into resource efficiency, institutional dynamics, and policy integration, they provide a roadmap for action through methods like integrated models and stakeholder engagement. The WEF-H nexus is not just a concept; it's a powerful framework for shaping a sustainable future.

For example, it enables consideration of ways to:

- i. Address energy security without impacting further on food or water resources.
- ii. Improve water security without increasing the energy burden of water management.
- iii. Create a more circular system by integrating food production with water and energy utilization. Wastewater can be treated and reused for irrigation, renewable energy can power agricultural processes, and food waste can be converted into biofuels or compost.
- iv. Encourage sustainable food production practices that prioritize nutrient-rich crops and diversified diets which can contribute to improved public health and reduced malnutrition.
- v. Create new green jobs in renewable energy, resource recovery, and precision agriculture, thereby meeting job creation ambitions in a sluggish agricultural economy without overextending water and energy resources.

The four most important interfaces in the water-energy-food-health (WEF-H) nexus are:

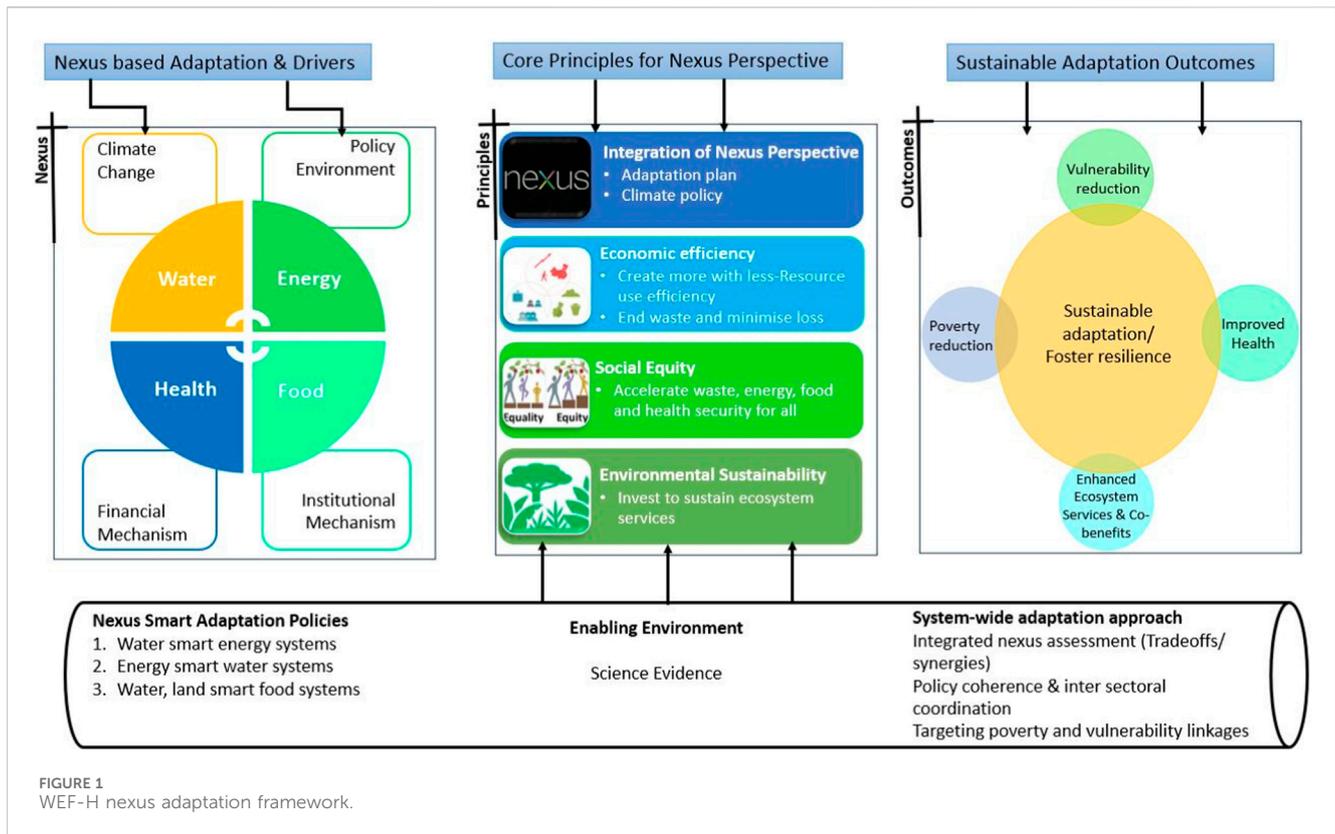
- Water which plays a vital role in both food and energy production, and for sustaining the ecosystems that support agriculture and other economic activities that are critical for food security.
- Energy, which is required for food production (especially irrigation) and for water supply, including the extraction, purification, and distribution of water.
- The role of food production as a consumer of land, energy, and water as well as their interlinkage with health.
- Health which is an intrinsic component of the WEF-H nexus, as the wellbeing of individuals is intricately linked to the quality and availability of water, the energy required for sustenance, and the nutritional aspects of food production. Recognition of the interconnections between addressing the challenges and opportunities within this interconnected system.

Agriculture, which is 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 also affect the water sector through land degradation, changes in runoff, and disruption of groundwater discharge (Shinde, 2017). Recognizing the intricate connections within the Water-Energy-Food-Health (WEF-H) nexus is paramount. Health, as a crucial facet of this nexus, is intricately linked to the availability and quality of water, the energy required for sustenance, and the nutritional aspects of food production. A holistic understanding of these interdependencies is essential for comprehensive and sustainable management within the WEF-H nexus.

4 Taxonomy of nexus approaches

According to Bian & Liu, (2021), there are four globally recognized nexus types:

- Water-energy: This nexus focuses on the interconnectedness of water and energy systems. For example, energy production often requires large amounts of water for cooling, while water distribution and treatment require energy (Wilson et al., 2021).
- Water-food: This nexus focuses on the connections between water resources and agriculture. Agriculture, particularly irrigation, is a major consumer of water resources. Consequently, fluctuations in water availability directly impact food production.
- Water-energy-food: This nexus adopts a holistic approach, bringing together the three core elements of water, energy, and food. It underscores the need for integrated planning and management, recognizing the interconnectedness and interdependence of these essential domains.
- Water-energy and climate: In this context, the nexus signifies the interplay between water, energy, and climate factors. It acknowledges the substantial influence of climate change on water resources, energy production, and food security. For instance, altered precipitation patterns can disrupt water availability, and extreme weather events have the potential to damage energy infrastructure and disrupt food supply.



chains. The discussion aims to clarify that the nexus represents the combination of these sectors, emphasizing the importance of a comprehensive understanding and strategic planning within the broader WEF-H context.

In recent years, additional nexus types have emerged:

- The Water-energy-food-ecosystems (WEFE) nexus: This nexus recognizes the pivotal role of ecosystems in shaping and sustaining the interconnections among water, energy, and food systems. Ecosystems provide indispensable services, including clean water, pollination, climate regulation, and biodiversity, which underpin the functionality of water, energy, and food systems (De Roo et al., 2021). The WEFE nexus highlights the profound interdependence between ecosystems and the essential sectors of water, energy, and food. It emphasises the need for holistic, integrated resource management approaches that recognize the intrinsic value of ecosystems in sustaining human wellbeing and promoting environmental resilience.
- Nuwayhid and Mohtar, 2022 contends that Water-Energy-Food-Health (WEF-H) nexus is a comprehensive framework that explores the intricate relationships between water resources, energy production, food systems, and public health. Unlike the WEFE which advances ecosystems as a critical physical component this nexus advances the health wellbeing. Equally it recognizes that changes in one domain can have significant impacts on the others though with an inherent interlinkage between physical components and human wellbeing. For instance, water is crucial for human

survival and agricultural production, while energy is essential for water treatment and food processing. Similarly, food quality and availability directly affect public health. This approach underscores the need for integrated, sustainable strategies in resource management and policymaking, emphasizing that decisions in one sector can have far-reaching consequences for the others. By embracing the WEF-H nexus, stakeholders can better address complex challenges related to resource scarcity, environmental sustainability, and community wellbeing through collaborative and innovative solutions refer to (Figure 1).

- Another nexus type, the water-energy-food-biodiversity-health (WEFBH) nexus, encompasses the complex interdependencies between water utilization, energy generation, food supply chains, and environmental and public health (Hirwa et al., 2021).

The interrelationships between the nexuses are illustrated in Figure 1. Essentially the framework for WEF-H Nexus not only captures the traditional WEF but encapsulates the health dimension as an equal sectoral lens to the nexus thus providing a holistic dimension. Policy framing is broadened to include issues around “healthy water,” “sustainable energy for health,” and “nutritious food for wellbeing.” Health metrics can be tracked alongside traditional WEF indicators to monitor the Nexus’s impact on health and identify areas needing improvement. Moreover, the nexus adaptation framework recognizes that the nexus is influenced by several exogenous factors including the impact of climate change, the policy sphere, institutional mechanisms as well as the financial mechanisms all of which

have an inherent effect on each of the sectors identified in this nexus.

Building on the foundation of previous nexus typologies that excluded health, the Water-Energy-Food-Health (WEF-H) nexus is a powerful tool at the socio-political level. It can alleviate tensions caused by poor coordination among non-state actors and inadequate service provision by the state. The WEF-H nexus also presents a unique opportunity to shift the focus from governance challenges to community empowerment, fostering self-reliance and sustainability. This empowerment includes showcasing alternative livelihood possibilities.

Furthermore, the WEF-H nexus has the potential to bridge the gap created by inequitable partnerships, whether rooted in gender, wealth disparities, racial divides, educational levels, or social statuses which have become pervasive in South African society. The nexus approach can contribute to what we term “societal hope,” instilling a profound belief within communities that they can chart a course away from hopelessness, even in the face of governance inefficiencies and limited access to opportunities. The principles thereof illustrated in [Figure 1](#) include environmental stewardship which advocates for investment in sustaining ecosystems services, social equity, resource use efficiency as well as the integrative perspective. These principles provide a foundation for merging effective pathways for successful implementation of NEXUS.

The adaptability of the Water-Energy-Food-Health (WEF-H) nexus, in contrast to other aspects of the economy, lies in its capacity to cater to communities with varying levels of knowledge and information. Unlike traditional economic frameworks, the WEF-H nexus is inherently versatile, offering a more inclusive approach that accommodates diverse communities. This adaptability stems from its comprehensive consideration of interconnected elements, allowing for nuanced solutions that address the complex and dynamic challenges present in the realms of water, energy, food, and health. By embracing a holistic perspective and fostering collaboration among stakeholders, including academics, civil society organizations, the private sector, government bodies, and international partners, the WEF-H nexus creates a platform that encourages innovation and technological advancements across multiple sectors and scales.

The WEF-H nexus holds the most promise for regions facing significant development gaps or struggling with complex socio-economic issues. It offers a powerful, unified approach to tackling these challenges and unlocking new opportunities. We characterize the opportunity presented by the WEF-H nexus as “extraordinary” due to its unique capacity to simultaneously address multiple facets of development challenges. The extraordinary nature lies in the nexus’s holistic approach, integrating water, energy, food, and health considerations. This all-encompassing strategy allows for comprehensive and interconnected solutions, offering a more effective and sustainable response to the complex socio-economic challenges and developmental hurdles that regions may face. The extraordinary nature of this opportunity is underscored by the potential for transformative and inclusive development outcomes, some of which are illustrated on [Figure 1](#) as sustainable adaptation outcomes.

5 Key characteristics of the water-energy-food-health (WEF-H) nexus approach

The WEF-H nexus approach is inherently accessible and requires no demystification. It is conceptually straightforward and designed to be inclusive, catering to individuals of all backgrounds and levels of expertise. Recognizing that, for the general public, concepts such as the WEF nexus and the WEF-H nexus may benefit from some explanation, we emphasize the fundamental nature of this approach. It relates to some of the most essential human needs: water, energy, food, and health. In this paper, we have identified ten salient characteristics that are recognized by many scholars and in the literature on the WEF-H nexus, aiming to enhance clarity and promote a more inclusive understanding:

- a. *Multi-sectoral focus*: The WEF-H approach unites a diverse range of stakeholders around a common set of goals, providing a platform for intentional and focused interaction. This cross-sectional coordination promotes convergence of perspectives and facilitates collaborative solutions.
- b. *Interconnectedness*: WEF-H nexus broadens the understanding of interlinkages ([Simpson and Jewitt, 2019](#)) recognizing the interdependencies ([Leck et al., 2015](#)) between sectors i.e., water, food, and energy.
- c. *Social embeddedness*. Beyond the physical/environmental connections of the nexus approach is the ability to recognize the social interactions among actors which may be referred to as social embeddedness interactions ([Srigiri and Dombrowsky, 2022](#)). WEF thus considers the political and cognitive factors that are central to policy change within sectors ([Weitz et al., 2017](#)).
- d. *Complexity*: The multifaceted nature and interactions between and within different subsystems ([Mutanga et al., 2016](#)) create complex dimensions that must be addressed. As a result, there is no one-size-fits-all model to deal with WEF-related issues ([Simpson and Jewitt, 2019](#)). Instead, time-bound and place-bound solutions are encouraged.
- e. *Governance modes*: Scholars studying the WEF nexus agree that integrative coordination across sectors, actors and levels of governance is essential, given the interconnected nature of the nexus ([Welsch et al., 2015](#)). It is important to note that the WEF-H nexus approach does not seek to replace focus and attention on actions (planning, investments, implementation, etc.) related to water, energy, food and health. Rather, it aims to break down the siloed approach to managing these resources and promote coherent and balanced planning and implementation.
- f. *Holistic Approach*: WEF-H nexus is a holistic approach that is consistent with well-established analytical frameworks such as Institutional analysis and development (IAD) framework ([Ostrom, 2010](#)) value chain analysis ([Villamayor-Tomas et al., 2015](#)), network of adjacent action situations (NAAS) ([Srigiri and Dombrowsky, 2022](#)), multi-criteria decision-making models (MCDM) ([Kumar et al., 2017](#)), Integrative Model ([Nhamo et al., 2020](#)), as well as systems dynamics models ([Wen et al., 2022](#)). All these tools share a common

structure for solving complex decision and planning problems, but their application and impact vary across sectors.

- g. *Implementation*: WEF-H nexus implementation is not an event, rather, it is a process that requires access to information about on-going plans and activities to ensure building-on and complementing those activities.

6 Barriers/bottlenecks for implementing nexus

The WEF-H is anchored in prioritizing the management of the four interconnected resources (water, energy, food, and health) in a sustainable way. However, implementing this nexus comes with different barriers and bottlenecks that hinder progress (detailed below and in Table 1).

South Africa currently lacks a singular policy document that explicitly addresses the Water-Energy-Food-Health (WEF-H) nexus. This does not necessarily imply a lack of commitment but reflects the intricate task of navigating trade-offs and resource constraints. This, position reflects the broader global context where numerous nations are yet to formulate comprehensive policies on the WEF-H nexus. In many instances, the implementation of WEF-H activities remains imbalanced, with sectors such as water, energy, food, and health often managed in a sectoral or “silo” approach (Nhamo et al., 2018). Despite the acknowledgment of the WEF-H nexus approach, these sectors frequently treat resources independently, guided by institutional structures (Adom et al., 2022). The reluctance to enforce integrative policies is a complex challenge influenced by trade-offs embedded across sectors, particularly in resource-limited countries. South Africa, being a water-scarce nation, has ambitious plans to transition from coal-based to renewable energy, including hydropower (Pegels, 2010; Oloade et al., 2017). This puts pressure on the water sector which has to prioritise maintaining the supply of its limited water resource to water provision, energy generation and agricultural production (the latter has a very high-water consumption factor of 62% due to irrigation (Adom et al., 2022)).

The reluctance to enforce integrative policies, driven by trade-offs across sectors in resource-limited countries like South Africa, poses significant challenges. As a water-scarce nation with ambitious plans for transitioning to renewable energy, the pressure on the water sector is pronounced (Rasul and Sharma, 2016).

Global climate change, and climate variability exacerbates the challenges of WEF-nexus in South Africa. Increasing aridity has a direct knock-on effect on food security (Schreiner and Baleta, 2015; Mabhaudhi et al., 2016), leading to hunger and a decline in the supply of nutritious food (Wlokas, 2008). Extreme weather events such as floods and heat waves also cause health issues such as food and waterborne diseases and heat stroke (Mabhaudhi et al., 2019) and exacerbates land degradation, especially of agricultural lands (Wlokas, 2008).

Water and land are key natural resources that are already under pressure from competing interests. Climate change exacerbates these challenges, as it increases the demand for resources. In regions where land and water are limited, an upsurge in multi-service projects aiming to tackle food insecurity and promote clean energy could exacerbate competition for these vital resources.

The lack of dedicated funding to provide integrated solutions is another reason why the sectoral approach persists, as the implementation of the nexus requires significant investment. The current funding landscape in South Africa prioritizes individual WEF sectors, with cross-sectoral funding streams being scarce (Mabhaudhi et al., 2018). This siloed approach creates several challenges among which includes:

- **Competing priorities**: Crises like the COVID-19 pandemic necessitate diverting limited resources to immediate needs like health and hunger alleviation (Wlokas, 2008; Mabhaudhi et al., 2019). This can exacerbate other critical issues like energy insecurity and poverty, further hindering progress on the WEF-H nexus.
- **Limited impact**: Sector-specific funding often fails to account for the interconnected nature of the WEF-H nexus, hindering the development of holistic solutions that address multiple challenges simultaneously.

The implementation of the WEF-H nexus requires innovative technologies and robust data, yet South Africa faces significant limitations:

- **Data scarcity and comparability**: Data availability is limited, and existing data often suffers from inconsistencies in spatial scales and temporal trends, hindering effective analysis and planning.
- **Technological lag**: Access to and expertise in innovative technologies like smart agriculture and early warning systems is limited, impeding the development of solutions to address challenges like climate change and disease outbreaks.
- **Amid unpredictable extreme weather events and the prevalence of diseases**, there is also a lack of innovative technologies tailored to alleviate the resultant impacts imposed by these events. Even though they come at a hefty cost, technologies such as smart agriculture (to alleviate a 15% decline in agricultural yields by 2050 if global warming increased by 2°C (Mabhaudhi et al., 2019)), early warning or detection systems and cutting edge health facilities are a necessity for an integrated response. Another bottleneck in this is that these innovative and sophisticated technologies require, trained personnel to operate them, which is still a scarce skill in the country.

Lack of functional, effective, efficient, and equitable partnerships or collaborations to drive implementation is another barrier. The implementation of the WEF-H nexus requires partnerships as individual experts rarely have expertise across all its dimensions. All this comes with effective communication across all relevant stakeholders including communities, technicians and government officials to promote dialogue among partners towards balancing the decision-making process. At the moment there is ambiguity regarding the roles of communities and relevant stakeholders in the implementation of the nexus framework (D. Naidoo et al., 2021). Some of the stakeholders are also in need of capacity development and awareness which hinders collaboration and results in a lack of stakeholder involvement in the nexus framework (Adom et al.,

TABLE 1 Identified bottlenecks drawn from literature and recommendations for implementing WEF-H Nexus.

Barriers	Description	Recommendation	References
Policy implementation	A lack of policy frameworks that facilitate the integrated management of water, energy, food and health	A need for policies that promote cross-sectoral linkages	Nhamo et al. (2018)
Funding	Rarely does one find a funding stream that seeks integration across related streams	Need for funding stream that seeks integration across related streams	Adom et al. (2022)
Working in silos	Individual sectors tend to work in isolation of other related sectors	A multi-sectoral approach needs to be practiced	Botai et al. (2021)
Natural resources	Increasing competing interests for limited natural resources	A balanced approach in the utilization of natural resources and educating the public about the importance of sustainable resource management	Adom et al. (2022)
Technical Expertise	There may be a shortage of expertise to implement the nexus program as individual experts rarely have expertise across all its dimensions	A need for technical experts trained to design and operate innovative technologies in the nexus	Adom et al. (2022)
Research and innovative modern technology	There is inadequate research and innovative modern technology to aid the implementation of the nexus	Supporting the advancement of research and technology	Decoppet et al. (2023)
Communication and knowledge	The WEF-H nexus is poorly communicated to the public and relevant stakeholders which lowers the understanding and attempts to bridge the knowledge gaps	Effective and transparent communication is needed to bridge the knowledge gaps	Mabhaudhi et al. (2018)
Political will	A lack of political will in the integrated approach due to biased interest to individual sectors	Promoting the intersectoral approach, which has significant benefits	Mabhaudhi et al. (2019)
Conflicts of interest and cultural beliefs	Different views, priorities and cultural beliefs among key stakeholders makes it difficult to reach a consensus in terms of implementation	Community and stakeholder involvement in policy development and establishment	Mabhaudhi et al. (2018)
Private sector involvement	Getting private sector's support in the implementation is imperative, yet it's a challenge	The private sector needs to see the benefits of investing in the nexus approach in order to be confident in it	Conway et al. (2015)

2022). For instance, about 73% of the participants in an interview study agreed that there are major gaps within stakeholder engagement in the nexus (Adom et al., 2022).

The WEF-H nexus faces the challenge of navigating complex political and socio-cultural landscapes, where historical biases towards isolated sectors hinder balanced implementation. Achieving consensus across spheres and sectors requires addressing these challenges and fostering equitable development.

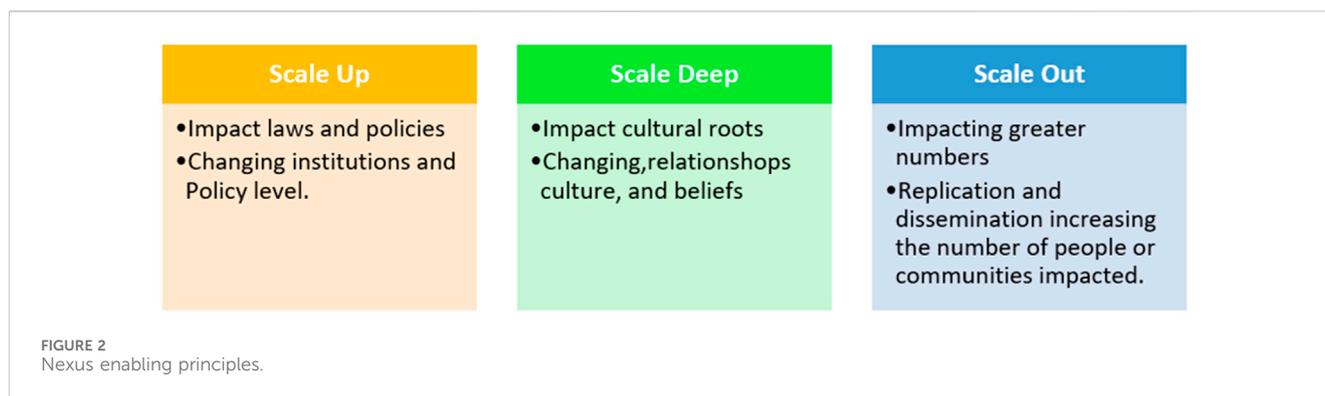
By design, the implementation of the WEF-H programme ideally requires a long period of time. It is possible that while implementing the WEF-H programme, the breadth and coverage of activities of WEF-H approach lend themselves to unintended delays that derail achievement of outcomes and impact. Pressured by the short terms in government, politicians and decision-makers may face pressure to show immediate results to meet political or economic agendas. This can lead to biased prioritization of short-term goals at the expense of the more comprehensive long-term goals of the nexus. Developing and revising policies to effectively enforce the WEF-H nexus demands meticulous consideration of numerous factors, inherently leading to a time-intensive process.

Getting the private sector to actively contribute to the implementation of the WEF-H nexus is another bottleneck. The focus of the private sector is profit. 'What is in it for us' has been the dominant and acceptable main focus of the private sector. The private sector is risk averse. Waiting for, encouraging, or coercing the government to absorb the inherent transactional risks has been one of the approaches that the private has used to minimize their exposure and ensure their profitability and sustainability. Despite

these basic attributes of the private sector, it is evident that most sections of the private sector are looking for opportunities where they can make a positive societal impact. The WEF-H nexus provides such an opportunity. This leaves us with the question: Why has the private sector not seized the opportunities to implement the WEF-H nexus, especially in communities wherein they operate? Is it likely that there are actions inherent in the implementation of the WEF-H nexus that are laden with risks that the private sector is not willing to absorb?

7 Enablers for implementing the WEF-H nexus

Several ingredients for transitioning from "nexus thinking" to "nexus doing" are required for a successful implementation of the WEF-H nexus. This approach holds immense potential to provide lucrative opportunities for South Africa. This paper adapts the scaling framework and classify the nexus under a three-pronged scaling principles system consisting of (i) scaling up, (ii) scaling deep, and (iii) scaling out as illustrated in Figure 2. Scaling up focusses on enabling factors that are policy and institutionally oriented, while scaling deep focus on culture and beliefs and scaling out centers on factors impacting greater numbers, the replication and dissemination of information on the WEF-H nexus. This results in an increased number of people or communities impacted. Lastly, scaling deep looks at enabling factors impacting on the cultural roots



including aspects such as changing relationships, culture, and beliefs.

For this procedural and transformative transition to happen, several enabling factors have been identified in the literature which foster the adoption and implementation of the WEF-H nexus. The first factor identified is the investment in Capacity Development. To unlock the full potential of the WEF-H nexus, robust capacity development initiatives are required across stakeholders, encompassing government agencies, researchers, and local communities (Chibarabada et al., 2022). These initiatives should encompass comprehensive training programs and knowledge-sharing platforms aimed at enhancing the understanding of nexus interlinkages. By equipping stakeholders with the necessary skills and insights, we empower them to make informed decisions that align with the holistic goals of the WEF-H nexus, thus catalyzing its effectiveness (Ramos et al., 2022). Local communities can also benefit from educational programs on sustainable water and energy practices, alongside leadership development workshops to empower them to participate in decision-making processes.

Secondly, mobilization of finance is also an imperative factor when it comes to the WEF-H nexus implementation. Securing finances is pivotal to translating the WEF-H nexus from theory into impactful practice, regardless of the chosen institutional approach (Hejnowicz et al., 2022). Southern Africa has witnessed a surge in research projects and publications concerning the nexus since 2013 (Naidoo et al., 2021). For instance, the Southern African Development Community-European Union (SADC-EU) nexus dialogue-funded project has been instrumental in driving the WEF-H nexus from abstract research to tangible action across southern Africa. This initiative has led to the organization of numerous workshops, symposia, and science-policy dialogues within the region. Such financial commitments not only facilitate research and data generation but also provide the necessary resources for practical interventions and policy implementations that promote the sustainable integration of water, energy, food, and health systems.

Decision Support Systems and Frameworks are also a necessary ingredient. The development of robust decision support systems and frameworks is paramount in navigating the complex terrain of the WEF-H nexus (Nhamo et al., 2020). These technological tools serve as indispensable guides for systematic analysis of intricate nexus linkages, enabling policymakers to scrutinize diverse scenarios and their potential ramifications on water, energy, food, and health

systems. Decision support systems are the linchpin of informed and effective decision-making within the multifaceted landscape of the WEF-H nexus, fostering data-driven, evidence-based solutions that optimize resource allocation, minimize vulnerabilities, and bolster resilience across these interconnected sectors.

Innovative Policy Frameworks have also been identified as one of the enabling factors (Naidoo et al., 2021). The dynamic nature of the WEF-H nexus necessitates adaptive and forward-thinking policy frameworks capable of accommodating its complexity. These policies should transcend sectoral boundaries, encouraging seamless integration and collaboration while emphasizing sustainability and resilience. The shared resources within the SADC region highlight the importance of harmonizing existing policies and linking them, as illustrated by the Revised Regional Indicative Strategic Development Plan. Such initiatives promote holistic resource management, acknowledge the interdependence of different sectors, and pave the way for comprehensive, cross-cutting policies that effectively address the WEF-H nexus's challenges.

Regional Cooperation is also an important enabling factor that has been identified within the literature (Decoppet et al., 2023). Recognizing that environmental and resource challenges often transcend national borders, robust regional cooperation is essential. Collaborative efforts between South Africa and neighboring countries can effectively address shared WEF-H nexus issues, enhancing stability and mutual benefits while ensuring harmonized resource management. Given the overarching nature of environmental and resource challenges, regional cooperation may serve as a fundamental pillar in addressing the complexities of the WEF-H nexus. The SADC regional integration framework (Saurombe, 2010) could transcend beyond trade to include developmental trajectories that have a bearing on WEF-H nexus. South Africa's geographical proximity to neighboring countries accentuates the necessity for collaborative endeavors. By forging strategic partnerships and alliances with neighboring nations, South Africa and other member states can collectively tackle shared WEF-H nexus challenges that transcend political borders. Such collaborative efforts foster stability, mutual benefit, and regional cohesion. Whether it is addressing transboundary water management, cross-border energy initiatives, harmonizing agricultural practices, or jointly responding to health crises, regional cooperation can yield synergistic solutions that are more effective and sustainable than isolated efforts within national boundaries. Additionally, regional

cooperation can lead to enhanced resilience in the face of resource-related uncertainties and bolster collective capacity for responding to emerging WEF-H nexus issues.

Political will is another important enabling factor that fosters the adoption and implementation of the WEF-H nexus. A bedrock of strong political will is fundamental to prioritize the WEF-H nexus and commit to sustainable resource management and public health. Such commitment provides the foundation for integrated policies and action plans that genuinely address the nexus's intricate challenges. A robust and unwavering political will stands as the cornerstone of meaningful progress within the WEF-H nexus. National leaders hold the key to prioritizing this integrated approach, committing to sustainable resource management, and safeguarding public health. Their dedication paves the way for the development and implementation of comprehensive policies and action plans that genuinely confront the intricate challenges posed by the nexus. It sends a resounding message that these issues are of paramount importance, transcending political cycles and short-term interests, and underscoring a commitment to the long-term wellbeing of both the environment and the populace.

Another necessary ingredient noted in the literature is the clear demarcation of WEF-H operational boundaries: Defining distinct operational boundaries for WEF-H initiatives is crucial as it ensures that roles, responsibilities, and accountabilities are well-understood, preventing overlaps or gaps in resource management, and fostering efficient and effective governance. This not only prevents wasteful overlaps and dangerous gaps in resource management but also fosters efficient and effective governance. By delineating the boundaries of action and influence, stakeholders can coordinate their efforts more effectively, resulting in streamlined operations and more impactful outcomes.

360-Degree stakeholder engagement that leaves no one behind is also another important enabling factor. This underscores the principle of inclusivity's paramount importance is recognized. Engaging all stakeholders, including marginalized communities, is essential for equitable resource allocation and access (Bruns et al., 2022; Hejnowicz et al., 2022). Such comprehensive engagement ensures that diverse perspectives and needs are considered. Engaging all stakeholders, without exception, is not only a moral imperative but also a strategic necessity. This comprehensive involvement ensures that the benefits and burdens of resource management are equitably distributed. Marginalized communities, often disproportionately affected by environmental and health challenges, must have their voices heard and their needs addressed. Inclusivity makes the WEF-H nexus genuinely holistic, drawing on a wealth of perspectives and insights to inform more equitable and effective policies and actions. To operationalize this approach, we propose several pathways for engaging all relevant stakeholders in the WEF-H nexus. Firstly, the establishment of inclusive platforms, such as community forums and online portals, can facilitate ongoing communication and collaboration. Secondly, targeted outreach and awareness campaigns can ensure that marginalized communities are actively involved. Thirdly, leveraging technology, such as mobile applications and social media, can enhance accessibility and engagement. Additionally, incorporating participatory approaches, like co-design sessions and citizen science initiatives, fosters a sense of ownership among stakeholders.

Unlocking the full potential of the WEF-H Nexus, demands breaking down siloed governance. Effective collaboration among government departments, private sector entities, civil society organizations, and academia creates a fertile ground for innovation which enables the sharing of knowledge, identify synergies, and address challenges holistically (Lazaro et al., 2022). Imagine a fertile ecosystem where engineers, farmers, policymakers, and community leaders, all contribute to cross-pollination of ideas. This is the power of a multidisciplinary approach to the WEF-H nexus, where collaboration sparks innovation and ensures no facet is overlooked. From policy blueprints to grassroots implementation, every strand contributes to a more comprehensive and impactful solution, ultimately leading to more sustainable and equitable outcomes for food, water, energy, and health.

Establishment of open access databases and encouraging data sharing can also positively impact on the adoption and the implementation of the WEF-H nexus. Data transparency and sharing are cornerstones of the WEF-H nexus approach. Open access databases facilitate the exchange of information, supporting evidence-based decision-making and research that can drive sustainable resource management and public health improvements (Mabhaudhi et al., 2021). Open access databases facilitate the seamless exchange of information among stakeholders, underpinning evidence-based decision-making, and research. With access to comprehensive and up-to-date data, policymakers and researchers can identify trends, track progress, and make informed choices that drive sustainable resource management and improvements in public health.

Innovative Technology is another enabling factor positively impacting on the adoption and implementation of the WEF-H nexus. Examples of these cutting-edge technologies include, but are not limited to, precision agriculture techniques that optimize water use, the integration of renewable energy sources to power nexus-related activities, and advanced health monitoring systems. Embracing cutting-edge technology within the WEF-H nexus enhances monitoring, data collection, and resource management. This includes the adoption of technologies that promote efficient water use, harness renewable energy sources, advance sustainable agriculture practices, and facilitate health monitoring, thereby driving innovation and progress across the nexus. Embracing cutting-edge technology is a catalyst for progress across the WEF-H nexus. By harnessing innovative solutions, stakeholders can drive meaningful change. Technology enhances monitoring, data collection, and resource management, leading to more efficient and sustainable practices that benefit both the environment and public health. It also fosters a culture of innovation, inspiring continuous progress within the nexus.

8 Conclusion

The exploration of water-energy-food-health (WEF-H) remains key in broadening our understanding of the nexus complexity. This article contributes to the body of knowledge which reveals a paradigm-shifting approach to addressing the intricate interdependencies among these critical sectors. Integration of the

health dimension goes beyond conventional WEF frameworks, as it introduces a comprehensive understanding of human wellbeing and resilience. The study contribute to the ongoing discourse surrounding the WEF nexus demonstrating the advantages of linking the health sector. By synthesizing insights from various disciplines, our work advances the understanding of how health interplays with water, energy, and food dynamics. This contribution positions the WEF-H nexus as an innovative solution to complex global challenges. To realize its full potential, there is a need for dedicated champions who can not only navigate the enablers and barriers outlined in this study but also translate concepts into actionable plans and sustainable programs. The success of the WEF-H nexus requires collaborative efforts from governments, stakeholders, and communities, providing a unique and impactful framework for addressing the multifaceted challenges at the intersection of water, energy, food, and health. South Africa, like many nations, aspires to build capable governance, but the complexity of the WEF-H nexus approach may strain government resources. The nexus approach acknowledges the existence of various policies, plans, systems, and programs, but also recognizes that their impact can be amplified when integrated into a cohesive implementation framework from the outset. This should not discourage governments to invest resources in the nexus approach but highlights the inherent challenges in aligning governance structures with its holistic nature.

While the Water-Energy-Food-Health (WEF-H) nexus presents a promising solution to urgent global challenges, its successful implementation necessitates meticulous planning, dedicated champions, and strategic governance. Recognizing the need for a nuanced approach, our paper emphasizes the imperative of capacity development, cross-sectoral collaboration, and the formulation of integrated governance frameworks. These elements are not merely suggested but they could be integral components that address the complexities involved. By strategically integrating these aspects into the implementation process, we ensure that the WEF-H nexus may be closer to reaching its full potential without imposing undue burdens on existing systems. Throughout the paper, we have enhanced the discussion, providing earlier argumentation to articulate the critical role of capacity development and integrated governance, thereby reinforcing the foundation for our proposed strategies.

In conclusion the WEF-H nexus presents an extraordinary opportunity to break the mold of traditional development paradigms. Its unprecedented focus on interconnectedness allows

us to address multifaceted challenges from water scarcity, energy and food security to health disparities in a truly comprehensive manner. This holistic approach promises not just incremental progress, but a paradigm shift towards sustainable and equitable development.

Author contributions

SSM: Conceptualization, Writing–original draft, Writing–review and editing, Funding acquisition, Investigation, Project administration. BKM: Writing–review and editing, Funding acquisition, Project administration, Supervision. SM: Writing–review and editing. MSM: Writing–review and editing. FVS: Writing–review and editing. TL: Writing–review and editing. SN: Writing–review and editing. TT: Writing–review and editing. JJ: Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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