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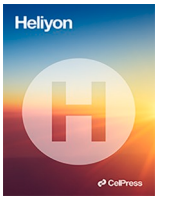

Review article

A bibliometric analysis assessing the water-energy-food nexus in South Africa

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ABSTRACT

The Water-Energy-Food (WEF) nexus is a paradigm that emphasises the interconnectedness and collaborative effects of water, energy, and food systems. This study presents a bibliometric analysis of South Africa's WEF nexus research landscape between 2011 and 2024 using the Scopus database. The article highlights the interconnectedness of sustainable development, resource management, sustainability challenges, and resilience strategies in the WEF Nexus in South Africa. The study also identifies critical research gaps in addressing socio-economic dimensions, policy and governance aspects, technological innovation, and human resource development within the WEF Nexus framework. The article reveals the transformative potential of blockchain technology in revolutionising resource management in South Africa. By leveraging blockchain's decentralised and transparent nature, the country can enhance efficiency, transparency, and sustainability in resource allocation and distribution.

1. Introduction

The water-energy-food (WEF) nexus has gained renewed attention and is recognised as a crucial strategy for sustainable resource management, particularly in climate-change-induced environmental challenges. The WEF nexus is a paradigm that emphasises the interconnectedness and collaborative effects of water, energy, and food systems. These sectors are vital for human welfare, poverty reduction, and sustainable development. The WEF nexus also influences other sectors, such as economic, social, political, and environment [1,2]. The WEF nexus strategy seeks to optimise resource efficiency, mitigate conflicts, and increase overall resilience in response to complex global issues by acknowledging the interconnectedness of the water, energy, and food systems. This approach is increasingly being recognised and embraced as a viable method for tackling the complex interconnections between these fundamental components of human well-being and environmental sustainability [1].

The interdependence and interactions of the water, energy and food resources has been identified and established for a long time and several efforts were made to provide a systems-based perspective that clearly recognises the intricate interlinkages, in order to better uncover and manage synergies and trade-offs between sectors which resulted into the development of several nexuses such as the Water-Energy (WE) and Water-Food (WF) nexuses [3]. The WE and WF nexuses developed by Gleick and Allan respectively were incorporated into policies and became a foundation for other emerging nexuses [4,5]. Shortly after the development of these nexuses,

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the Twin approach to address food shortages was established by the Food and Agriculture Organization (FAO) while the Integrated Water Resources Management (IWRM) also emerged as an alternative framework to manage water resources [6]. However, these framework were critiqued due to integration challenges, inadequate measurements and resource allocation, tending overlook the interconnections with other resources leading to isolated management policies and conflicting outcomes for each resource. Additionally, the IWRM framework was argued to be too broad, making it difficult to implement effectively. Some critiques also stated that it lacked clear, actionable guidelines [7,8]. As competition for WEF resources intensified, it became glaring that existing framework and nexuses were incapable of ensuring sustainability and resource management in the sectors due to their lack of comprehensiveness [9,10]. Consequently, this led to the emergence of a new nexus tagged the WEF Nexus during the 2011 Bonn Conference whose scope included all the three sectors and acknowledging their intricate interconnections [6].

[11] affirmed that the nexus approach is an integrated approach that encompasses management and governance across different sectors and scales. Connections between the WEF sectors, also known as the FEW (Food-Energy-Water) Nexus [12–14], are becoming an important academic, policy, and societal topic that is increasingly being discussed in global society, including the relationship with ecosystems, livelihoods, and the economy. The WEF security nexus approach addresses the pressing challenge of managing water, energy, and food resources simultaneously while achieving multiple conflicting objectives without compromising any sector's resource base [11]. Studies by. [2,15] revealed that factors such as population growth, accelerated urbanisation, shifting consumer preferences, economic development, international trade, cultural and technological advancements, and climate change are mounting pressure on the global demand for WEF resources. Additionally [16], stated that the WEF sectors had been impacted by the COVID-19 pandemic with short and long-term effects such as sectoral supply disruptions, localisation of production, and demand fluctuations on the WEF Nexus.

The WEF Nexus is crucial to achieving the Sustainable Development Goals, particularly Goals 2, 6, and 7 [17]. Total eradication of hunger (SDG 2) requires a holistic approach that views the problem from a system perspective [18]. Similarly [19], pointed out that the WEF nexus is a platform that can ensure the availability and sustainable management of water resources globally to give the world's population access to clean water and sanitation. Furthermore, the WEF nexus supports access to affordable, reliable, sustainable, and modern energy for all [20]. affirmed that one in five people lack access to electricity, and as the demand continues to rise, there is a need for a matching increase in the production of renewable energy globally. Therefore, the WEF nexus is critical to achieving affordable and clean energy for all.

The WEF nexus is crucial to achieving water, energy, and food security and addressing resource interdependencies. Millions of people lack access to safe drinking water, energy, and safe food sources [21]. Water security, which includes access, safety, and affordability, is said to have direct implications for the energy and food sectors. Limited or intermittent electricity and fuel supply can affect water access, while competing for water in food production can also restrict availability. Activities such as fossil fuel extraction and intensive agriculture also degrade water quality. A key consideration in the nexus assessment is that achieving the security of one resource sector should not compromise an adjacent resource sector [2,20]. The WEF nexus approach can increase water, energy, and food security by increasing efficiency, eliminating trade-offs, developing synergies, and improving governance across sectors, having recognised the interconnectedness of the water, energy, and food sectors.

The WEF nexus is also critical to natural resource management and climate change policy because social changes drive WEF demand increase, and continuous environmental changes are likely to impact water supply or accessibility [15]. Economically, the nexus approach improves viability, resilience, and innovation while reducing risks and costs associated with climate events. Socially and environmentally, it improves public health, employment, water services, ecosystem conservation, and regional cooperation [22,23]. The WEF nexus approach helps optimise resource use, minimise conflicts, and regulate unsustainable practices, improving water security, reducing pollution, and improving ecosystem services. In contrast to integrated water resources management (IWRM), the WEF nexus emphasises non-linear system analysis and dynamic feedback across water-intensive industries [24].

Recently, there has been a noticeable increase in the attention given by many nations to the WEF Nexus, aiming to safeguard resource security and promote sustainability. In Europe, Germany has become a leader in promoting renewable energy and sustainable agriculture to reduce resource consumption and greenhouse gas emissions. In the Middle East, water-scarce countries such as Jordan and Israel have also adopted innovative water desalination and re-use technologies that allow them to support agriculture and energy production [25,26]. In response to the increasing energy requirements driven by its expanding economy, China has strategically integrated the WEF Nexus framework into its policy framework to optimise water use in agriculture, improve energy efficiency, and promote renewable energy sources such as solar and wind [26]. Similarly, India has enacted policies to improve water management and energy conservation in agriculture to increase food security and reduce environmental impact [27]. African countries, such as Ethiopia, are also currently investigating the WEF Nexus as a means to address the issue of water shortages, improve irrigation techniques, and promote the utilisation of renewable energy sources for improved energy accessibility [28].

Existing literature on the WEF Nexus has produced valuable findings in increasing awareness and contributing to a better understanding of WEF interdependence, which is critical for sustainable resource management [19,29–32]. Several studies have also identified WEF Nexus obstacles, such as policy gaps, insufficient frameworks, and data issues, resulting in the development of frameworks, policy changes, research, and collaborations. However, the WEF Nexus is still plagued by data scarcity and a lack of comprehensive frameworks that have hampered its comprehensive operationalisation. Furthermore, there has been a lack of research translating theoretical ideas into practical, implementable models. Geographical biases in coverage areas have also hampered the implementation of the WEF nexus in some locations, such as Sub-Saharan Africa, notably South Africa. This study will address geographic bias in WEF nexus literature by identifying specific research contributions and shortcomings, which will enhance the knowledge of local issues and innovations and guide focused research and policy responses for sustainable development in South Africa.

South Africa, a water-scarce country with limited arable land and abundant mineral resources, faces significant challenges in the WEF nexus. Water scarcity is a pressing issue due to irregular rainfall patterns, droughts, and increased water demand from growing populations and economic activities. Irrigated agriculture accounts for 30 % of the country's crops and 75 % of agricultural water use [23]. The majority of electricity, around 86 %, is generated from coal-fired power stations, which consume significant amounts of water for cooling and hydropower, creating competition for water resources and affecting its quality. The agricultural sector is also crucial for food security but requires significant water and energy input. Coal mining and farming activities also threaten the quality and availability of water and energy in places such as Mpumalanga while competing for land [33]. The Olifants River catchment, impacted by extensive coal mining, also suffers from poor water quality, while access to improved drinking water in Mpumalanga has decreased, raising concerns [20].

[34] stated that South Africa ranked 72nd out of 170 countries with a WEF nexus index of 56.1 when 21 WEF variables were used to generate the WEF nexus index. While this represents remarkable progress, the country still faces significant challenges in managing its water, energy, and food systems. [35] stated that South Africa portrays a lack of policy direction in the principle and execution of the WEF nexus. Similarly [36], described the country as an energy-intensive, water-scarce, and food-deficient country, stating that the country has not taken full advantage of the Nexus approach to solving the problems with food, energy, and water. However [37], stated that more WEF research and analyses can result in solutions and policies. Additionally [36], stated that there is a need for further collaboration and synergies in the WEF nexus.

Several review studies have been carried out on the WEF nexus. However, there has been a shortage of reviews identifying research patterns or publication trends focused on South Africa. This study identified 22 review studies, with only five explicitly focused on South Africa, revealing a dearth of WEF nexus reviews in South Africa. An analysis of the previous reviews reveal that the reviews have been focused on the interaction between the WEF nexus and their implications on economic activities such as coal mining, agriculture, food insecurity, government policies, climate change/risk and sector-specific policies. Additionally, the reviews have been characterised by a lack of standardised methodologies as most of the reviews embark on a narrative review of policies and frameworks, with only a few adopting a systematic or bibliometric procedure.

However [38], in his bibliometric review identified WEF Nexus challenges and general themes peculiar to African countries. He stated that identifying WEF Nexus research themes will be crucial in operationalising the WEF Nexus. The study revealed that WEF nexus research among African countries differs. While this study is vital to the progress of WEF nexus research in Africa, it reveals a geographical bias. The findings of the study are also supported by [37]. It is, therefore, essential to establish research trends and analyse gaps peculiar to South Africa to understand the present state of research. Similarly, in a recent bibliometric review by [39], the study identified 65 articles published in Africa and 18 in South Africa between 1980 and 2021. The study also identified research trends and themes in Africa but failed to identify specific research trends and themes focused on South Africa. Additionally, there has been an increase in the number of publications generated from 2021 till date. It is, therefore, essential to understand the research trends, gaps and themes specific to South Africa while considering the increase in research publications. These identified trends and themes will reveal research areas that require further collaboration and attention to advocate for targeted policies and a holistic approach to addressing these challenges. Given these concerns, this study will achieve the following objectives.

a. analyse the WEF Nexus themes in South Africa.
b. identify research gaps in South Africa's WEF Nexus research.
c. propose a WEF nexus Management Approach.

2. Materials and methods

This study used bibliometric analysis to evaluate the themes of the WEF nexus in South Africa. A study byManoj Kumar. [40] described bibliometric methodology as analysing bibliometric data to reveal emerging article trends, assess collaboration patterns and journal performance, and investigate intellectual structures within a research domain. The authors emphasise that such analysis establishes a solid foundation for advancing research, empowering researchers and scholars to identify knowledge gaps, gain a comprehensive overview of a research area, and effectively position their contributions. Consequently, this research employed bibliometric analysis to identify and examine themes related to the WEF Nexus in South Africa.

To accomplish this, publications from the Scopus database were used because of its comprehensive coverage of literature, including journals, conference proceedings, and books, which enables authors to provide a holistic view of research trends, and it has been stated as a reputable source for high-quality bibliometric data source [41]. Additionally, it includes reputable journals indexed in major citation indices, ensuring the reliability and quality of the data being analysed. Using a single database like Scopus also ensures data retrieval and analysis consistency, minimising potential biases from multiple sources [42,43].

The study adopted the Boolean phrase "Water" AND "Energy" AND "Food" AND "Nexus" to retrieve relevant articles published between 2011 and 2023. The article was limited to South Africa. The search produced one hundred and thirty-five (135) articles. The period between 2011 and 2023 was selected to study the Water-Energy-Food Nexus in South Africa as it incorporates significant developments such as policy changes, impacts of climate change, and changing resource demands. This time frame also enables an exhaustive review of recent trends and emergent challenges, ensuring that the analysis is all-encompassing, starting from the evolution of WEF Nexus at the Bonn conference and relevant to South Africa's current circumstances. The publications were downloaded in CSV files. The bibliometric data downloaded included citation information, bibliographical information, titles, abstracts, keywords, and funding details. The CSV file was imported into the Vosviewer software to analyse the bibliometric data, thereby identifying the research themes of WEF Nexus. Table 1 reveals the breakdown of the articles retrieved in the bibliometric analysis.

3. Results and discussion

3.1. Trends in publications of WEF nexus in South Africa

The Scopus database identified 135 publications on the water, energy and food nexus in South Africa between 2011 and 2023. Fig. 1 provides an overview of the landscape of publications in South Africa spanning the decade from 2013 to 2023. Studies revealed that WEF Nexus research began in 2007 globally and 2008 in Africa; however, WEF Nexus research only began in 2013 in South Africa as there was no record of academic publication on WEF Nexus in South Africa. This finding aligns with the findings of [39]. However, between 2013 and 2016, South Africa contributed nine (9) publications on the field of WEF nexus, and the number of publications grew slowly, reaching 55 in 2022**.** The Publication output was highest in 2022 with 40 articles; while the reason for this is unknown, it may be attributed to increased awareness and funding on sustainable development and policy initiatives on resource management may have gained traction, driving increased research interest. The study also revealed that the Water Research Commission has the highest funding of WEF Nexus research with 22 articles, while the University of KwaZulu-Natal has the highest affiliation with 46 articles. While this may suggest a strong institutional focus on WEF Nexus research in South Africa, it reveals the importance of more collaborative partnerships between scholars, research institutions and funding bodies to advance knowledge and address WEF challenges.

3.2. WEF Nexus Themes in South Africa

The Vosviewer software was used to analyse the Bibliometric information downloaded from the Scopus database. The themes for WEF Nexus in South Africa were derived using the keyword co-occurrence of the publications in Vosviewer. The cluster themes were selected by conducting a comprehensive study of the keywords in each theme. Each thematic cluster reflects a distinct emphasis area or subject within the larger WEF Nexus framework, and keywords were grouped based on conceptual similarities and importance to the WEF Nexus. This function factored in all authors and indexed keywords at full counting, highlighting the trends and concepts in the WEF Nexus in South Africa. In the co-occurrence analysis of all keywords, 47 out of 1167 keywords met the threshold of at least 5 occurrences, producing four clusters, 729 links, and a total link strength of 1752. The Bibliometric analyses of the keywords resulted in four (4) thematic clusters revealing the themes associated with the WEF Nexus, as shown in Fig. 2.

The first thematic cluster is in red with 14 keywords (see Fig. 2). They are Africa, agriculture, article, energy resource, energy use, human, hydropower, planning, south Africa, water management, water resources, water supply, and Water-Energy-Food nexus. The second thematic cluster in green colour includes 12 keywords, which are economic and social effects, economics, energy security, food production, food security, investments, irrigation, optimisation, population statistics, renewable energy, sustainability, and water energy. The third thematic cluster is in blue with 11 keywords: Climate change, conceptual framework, decision making, energy, food, governance approach, nexus, poverty alleviation, sustainable development, wastewater treatment, and water. The fourth thematic cluster covers 10 keywords in yellow: adaptation, food supply, livelihoods, resilience, resource allocation, resource management, resource security, southern Africa, sustainable development, and WEF nexus.

Red thematic cluster- Sustainable Development: This first cluster presents sustainable development as a central theme as its keyword captures the interconnectedness of water, energy, and food resources in Africa's development, encompassing aspects such as agriculture, energy resources and use, water management, and planning. Additionally, it highlights the human dimension by addressing the impact on communities and the need for integrated approaches to ensure sustainable resource utilisation and supply, particularly in regions like South Africa. This theme corroborates the assertions of [17] who stated that the nexus of water, energy and food is an integrated approach towards sustainable development. This theme brings to focus the multifaceted approach to achieving sustainable development in South Africa. It highlights the crucial role that agriculture, energy resources, water management, and human well-being will play in achieving sustainable development. A critical view reflects interconnectedness among the keywords, implying that addressing one aspect can have cascading effects on others. For example, improving water management practices can enhance agricultural productivity, support renewable energy development, and promote human well-being. Therefore, focusing resources on these keywords would allow for targeted interventions that can yield significant and lasting impacts. By prioritising investments in critical sectors such as agriculture, energy, and water management, South Africa can leverage its resources more effectively to achieve sustainable development goals and enhance resilience to climate change, resource scarcity, and socio-economic challenges.

Table 1
Document considered for WEF Nexus Bibliometric Analysis.

Document Type	Number of Document
Articles	67
Book	5
Book Chapter	34
Conference Paper	3
Editorial	3
Review	22
Short Survey	1

Source: Research Survey (2024)

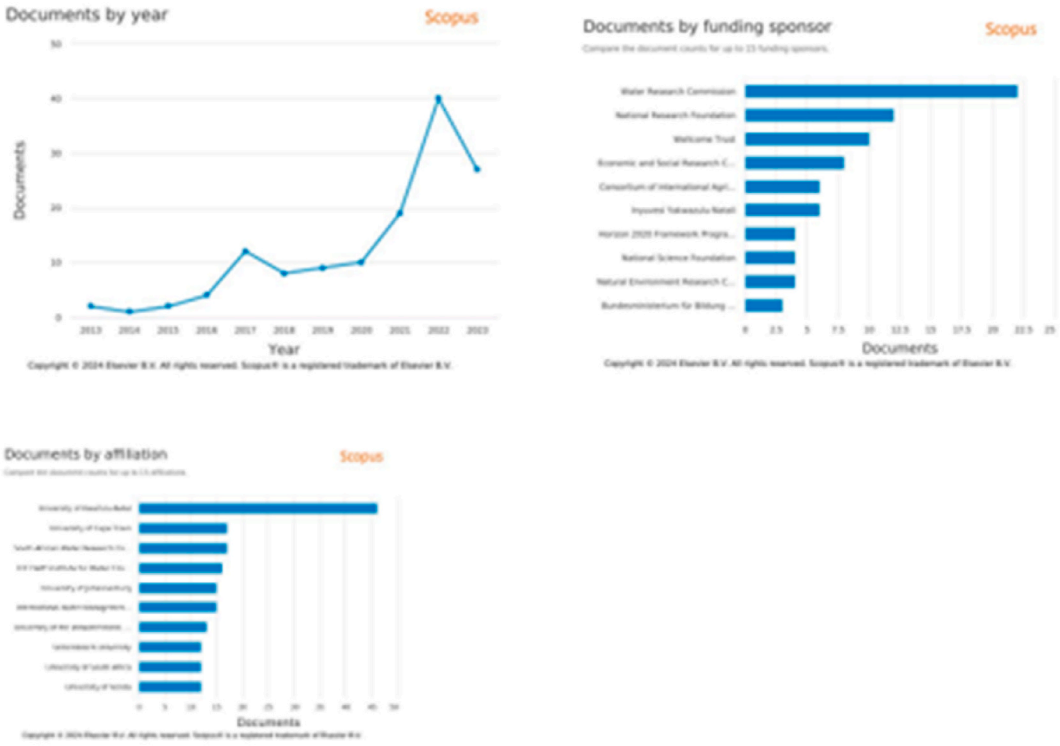

Fig. 1. The publication trend of WEF nexus in South Africa.
Source: Research Survey (2024)

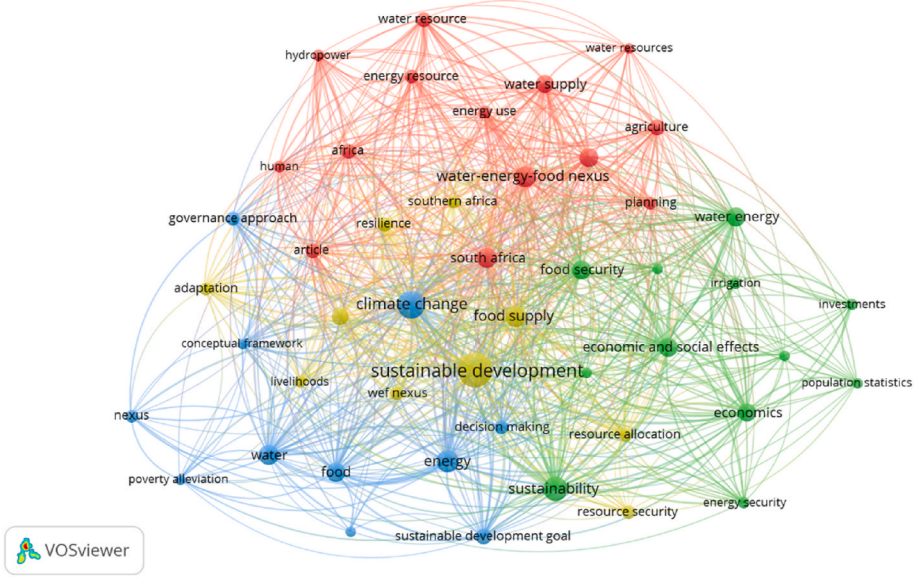

Fig. 2. Wef nexus themes.
Source: Research Survey (2024)

Focusing on these keywords would also stimulate innovation and technological advancement in the sectors that serve as pivotal sectors in the advancement of South Africa's economy. Agriculture, energy, water management, and human development drive progress towards economic prosperity, social equity, and environmental sustainability. South Africa can unlock its full potential and pave the way for a brighter and more sustainable future by concentrating resources on these critical areas and adopting integrated and holistic approaches.

Green Thematic Cluster- Resource Management. This cluster identifies Resource Management as its central focus with keywords such as economic and social effects, economics, energy security, food production, food security, investments, irrigation, optimisation, population statistics, renewable energy, sustainability, and water energy, all of which are crucial components of managing resources in a sustainable and environmentally responsible manner. Resource management is critical in the economic development and social well-being of any nation, including South Africa. Effective management of resources is paramount to achieving sustainable economic growth and societal progress in South Africa, a country rich in natural resources yet facing significant challenges. Efforts focused on energy security and renewable energy are critical for sustaining economic activities and improving living standards. [44] stated that South Africa's heavy reliance on coal for energy production poses challenges in terms of environmental sustainability and energy security. Consequently, transitioning towards renewable energy sources such as solar, wind, and hydroelectric power holds promising advancements, as revealed by [45]. Similarly, efforts must be directed towards food production, security, and irrigation management. These efforts geared towards resource management are crucial for reducing greenhouse gas emissions, enhancing energy security, improving agricultural productivity, enhancing access to markets, investing in modern irrigation systems, promoting water-saving technologies, and promoting sustainable development.

[46] stated that concentrating resources on key priorities such as renewable energy, sustainable agriculture, and water management is essential for achieving long-term economic prosperity, environmental resilience, and social equity. It is imperative to state that efficient resource management can significantly enhance South Africa's economy by promoting sustainable development, reducing poverty, and fostering inclusive growth. By prioritising investments in renewable energy, improving agricultural productivity, and implementing effective water management strategies, South Africa can unlock its full economic potential while addressing pressing socio-environmental challenges.

Blue Thematic Cluster: Sustainability Challenges: South Africa faces numerous sustainability challenges that threaten the WEF nexus's operationalisation and the well-being of its people and the environment. Among these challenges are climate change, energy and water scarcity, poverty, inadequate wastewater treatment, and governance approach, which are keywords in the blue thematic cluster. The assertions are further re-iterated as rising temperatures, erratic rainfall patterns, and extreme weather events have been stated to exacerbate water scarcity, agricultural productivity, and public health [47]. Similarly, the energy sector faces challenges such as dependency on fossil fuels, energy poverty, and environmental degradation, threatening sustainable development [44]. [48] stated that South Africa is afflicted with both hunger and malnutrition, with one in every four residents enduring hunger and 26.5 % & 70 % of children and adults stunted, respectively. Concentrating resources on these keywords is essential for effectively addressing sustainability challenges in South Africa. South Africa can develop integrated and holistic solutions that promote resilience and prosperity by focusing on climate change, energy, food, governance approaches, nexus thinking, poverty alleviation, and wastewater treatment. Furthermore, strategically allocating resources to these critical areas can maximise impact and leverage synergies between different sectors, leading to more sustainable outcomes.

Yellow Thematic cluster: Integrated Resilience strategy: This theme encompasses the interconnected aspects of adaptation, food supply, livelihoods, resilience, resource allocation, resource management, and resource security within South Africa. It emphasises the importance of adopting sustainable development practices that address the complex interdependencies of water, energy, and food resources while also prioritising the resilience of local communities and ecosystems. By employing integrated approaches and collaborative efforts, stakeholders can work towards achieving sustainable solutions that promote both environmental conservation and socio-economic development in the region. Adaptation is a fundamental aspect of resilience, especially in climate change and other environmental disruptions. In South Africa, adaptation measures encompass strategies to mitigate the impacts of droughts, floods, and other extreme weather events on agriculture, infrastructure, and communities. A focus on adaptation ensures that the nation can effectively respond to changing environmental conditions and minimise vulnerabilities.

Food supply and livelihoods are intertwined with adaptation and resilience. South Africa's agricultural sector is vital for food security and rural livelihoods. Thus, a resilient food supply chain is essential for safeguarding food security and economic stability. By enhancing agricultural resilience through sustainable farming practices, improved infrastructure, and diversified livelihood opportunities, South Africa can bolster its ability to withstand shocks and sustainably support its population. Resource security is also closely linked to resilience, as access to essential resources such as water, energy, and food is fundamental to economic development and societal well-being. By prioritising resource security, South Africa can mitigate risks associated with resource scarcity, ensuring stability and resilience in the face of future challenges.

Concentrating resources on these keywords within the Integrated Resilience strategy would significantly enhance South Africa's economy. South Africa can create a more robust and resilient economy by investing in adaptation, food security, livelihoods, resilience-building measures, resource management, and sustainable development. Furthermore, by addressing the interconnected challenges highlighted by the WEF nexus and prioritising collaboration within the region, South Africa can position itself as a leader in sustainable development and resilience-building efforts, thereby enhancing its global competitiveness and attractiveness for investment.

3.3. Research gaps in South Africa's WEF nexus research

The prevalence of the keywords in South African WEF nexus research indicates a strong emphasis on addressing sustainable development, resource management, challenges, adaptation, and the interdependence of water, energy, and agricultural systems. The research has focused on resilient and sustainable systems that can withstand environmental changes and support the well-being of present and future generations in South Africa. The keywords also strongly emphasise environmental and technical aspects but reveal a relative disregard for the socio-economic dimensions of the WEF nexus and issues of equity and access. It also exposes a lack of research addressing the uniqueness of South Africa within the WEF nexus, such as regional resource availability and cultural factors that may

impact the operationalisation of the WEF Nexus.

The analysis also did not explicitly mention keywords associated with policy, governance, or institutional aspects of WEF nexus management, disregarding the importance of effective policies and governance mechanisms in implementing sustainable solutions. Additionally, keywords are not associated with innovation, technology adoption, and best practices. The analysis highlights a significant deficiency of research on human resources skills, education, and capacities in the WEF Nexus in South Africa. Although the nation is dedicated to promoting knowledge in this subject, there is a noticeable lack of publications focusing on the vital issue of human capital in the WEF Nexus. While the number of publications on the WEF Nexus is gradually rising, they have failed to address the human resources aspect sufficiently.

The lack of study on human resources in the WEF Nexus is a significant research gap that needs to be explored. This finding is corroborated by [49] who affirmed that there is a scarcity of WEF Nexus research that examines the dynamic effects of anthropogenic systems on the future paths of the nexus. The role of human resources is crucial in promoting innovation, executing sustainable practices, combating sustainability challenges, promoting resilience, and assuring the effective management of water, energy, and food resources. Since the increasing human interference in environmental processes has resulted in significant alterations in WEF resources availability, then it becomes imperative to also address human interactions in the WEF Nexus, and seek human efforts to address WEF challenges [50]. The insufficient focus on the workforce's skills, education, and competencies may impede the operationalisation of the WEF Nexus and abort the successful integration of policies and practices. Hence, recognising and addressing the human aspect is crucial for sustainable development as the WEF Nexus is emerging as a new focal point of study. Future studies should investigate the impact of education and skills development on the resilience and efficiency of the WEF Nexus and identify the requisite skills, education and capabilities required for effective operationalisation.

3.4. Propose a WEF nexus Management Approach

The research gaps in South Africa's WEF nexus reveal a lack of research on human resource capabilities, innovations, and technologies that can operationalise the WEF nexus in South Africa. In line with these findings, this study proposes that the Human Capital Development and Technological Adoption Approach will enhance the operationalisation of the WEF nexus in South Africa. This approach systematically addresses the interrelations and interactions within the nexus by emphasizing the integration of human expertise and technological advancements. The interaction between human capacity and technology will enable a holistic understanding of how resource use in one domain affects others and how these resources can be co-managed to attain security and sustainability. The use of technology can reduce water usage, food waste and energy consumption, while human expertise will ensure that these practices are effectively implemented and adapted. This integrated approach supports sustainable and efficient resource management in the WEF nexus.

3.4.1. The Human Capital Development Approach

The Human Capital Development Approach for implementing the WEF Nexus in South Africa is a management strategy that will consider the development of essential competencies and knowledge among resource management professionals and stakeholders. The approach will include training programmes, capacity development activities, and educational campaigns focused on South Africa's WEF Nexus unique needs. This approach will enhance the development of an educated workforce capable of recognising and resolving the linkages between the water, energy, and food industries. Gaining requisite knowledge will allow the translation of Nexus theories and frameworks into practicable models, addressing one of the challenges of the Nexus identified by [38,51–53]. It will also encourage the application and adoption of technology for sustainable resource management, such as smart agriculture and efficient water and energy usage, which will address the technological lag challenges identified in previous studies [54–57]. The approach will require collaboration between stakeholders, educational institutions and industry professionals to provide comprehensive training programmes. These programmes would address multidisciplinary themes and capacity building to operationalise the WEF Nexus. The approach will invest in human resources and allow South Africa to implement comprehensive solutions to WEF Nexus concerns successfully.

3.4.2. The Technological Adoption Approach

This study also revealed a lack of innovation and technology adoption in the WEF Nexus research theme in South Africa. This finding collaborates with existing research identifying technological lag as a WEF Nexus challenge. Adopting innovative 4IR technologies will play a critical role in facilitating effective resource management and innovative change within the Nexus in South Africa. Blockchain technology has emerged as a viable 4IR technology for revolutionising several industries, including resource management. Blockchain technology, made popular by the Bitcoin digital currency, is a distributed and decentralised record-keeping system that records transactions via a network of computers. Each transaction is saved in a "block" connected to previous transactions, resulting in a chronological chain of blocks. The blockchain relies on a consensus method in which transactions are approved by network members, removing the need for middlemen such as banks or governments [58,59].

Blockchain functions on a peer-to-peer network, with each member retaining a copy of the ledger. This decentralised structure increases transparency and resilience since there is no centralised point of control or failure [60]. Transactions registered on the blockchain are available to all network participants, which promotes transparency and trust. Furthermore, blockchain's unalterable nature assures that a transaction cannot be changed or removed once recorded. It also uses cryptographic techniques to safeguard transactions, making it resistant to fraud and manipulation. Blockchain's distributed nature makes it more secure than centralised solutions [61,62]. Several pilot projects and case studies throughout the globe indicate the potential and usefulness of blockchain

technology in resource management. The blockchain-based water trading platforms aimed to improve transparency and efficiency in water markets in the USA, Australia, Chile, and China [63]. Using blockchain for tracking and certifying produced food products also enhances transparency and consumer trust [64]. The deployment of blockchain-based smart meters in Sweden to enable real-time energy trading among households, reducing energy waste and promoting renewable energy integration [65,66].

In South Africa, where challenges related to water scarcity, energy access, and food security are prevalent, blockchain technology holds immense promise for addressing these complex issues as revealed in Fig. 3. Blockchain provides transparent and secure transactions using decentralised record-keeping, which fosters accountability and trust in resource management [67]. Smart contracts automate agreements, streamline procedures, and reduce inefficiencies. Peer-to-peer trading networks allow for direct trades of surplus resources, which improves utilisation and reduces waste. Blockchain technology encourages sustainable practices that promote equitable resource access by increasing transparency, efficiency, and accountability [64]. Furthermore, blockchain can assist in solving sustainability issues such as water scarcity, energy availability, and food insecurity by allowing for more efficient resource

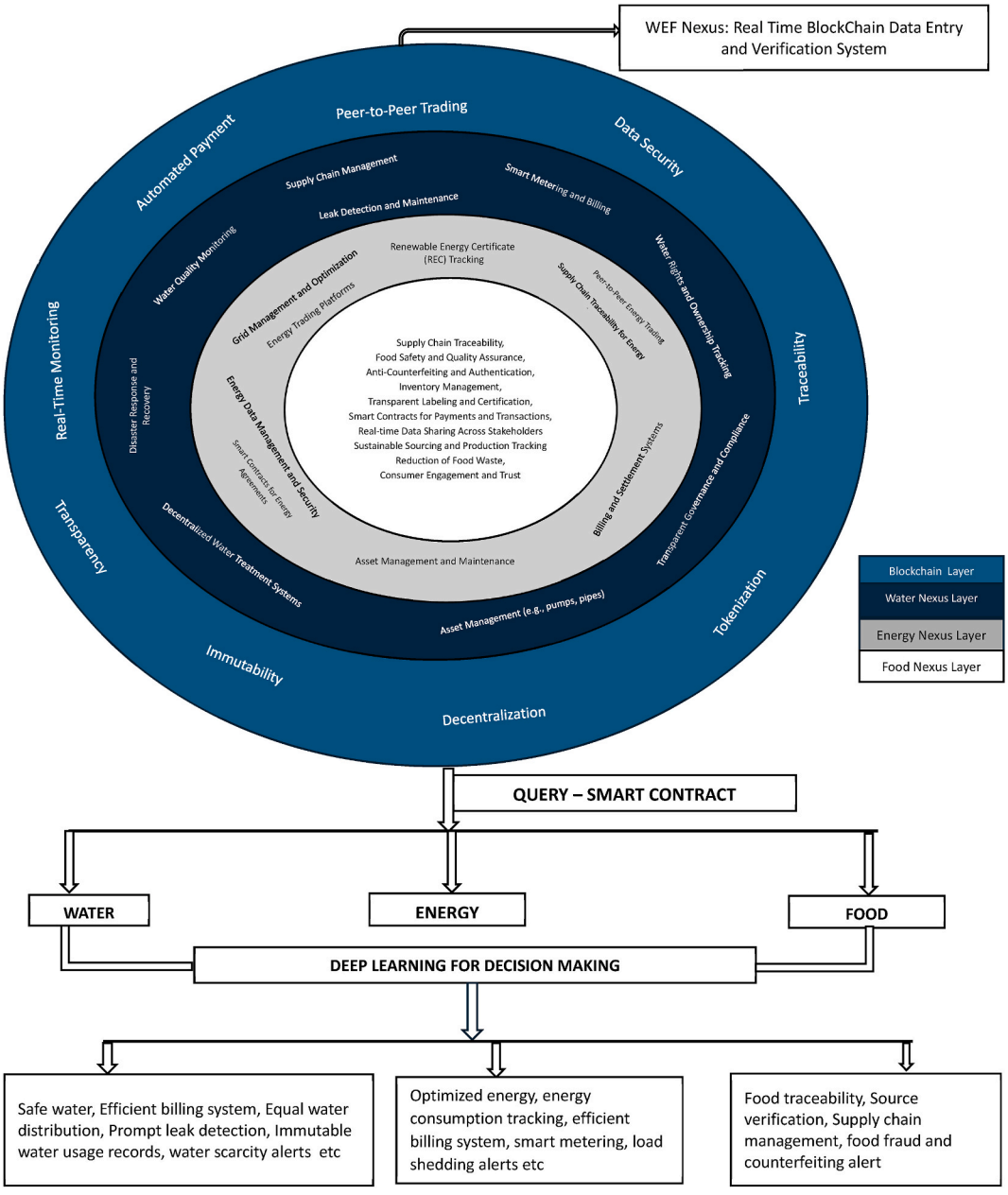

Fig. 3. WEF Nexus Blockchain Verification System.
Note: This Figure reflects the integration of blockchain technology to aid in verification of WEF resources to enhance efficiency and sustainability. The figure was developed by Authors.

management and allocation [59,68].

By leveraging blockchain's unique features, South Africa can enhance the management of WEF resources in the following ways.

1. Blockchain can enable decentralised record-keeping for WEF resource transactions, reducing the need for centralised authority and increasing transparency [69]. emphasises the potential of blockchain to disrupt established governance paradigms by enabling decentralised decision-making and lowering corruption cases.
2. Blockchain can be used for automated transactions: Blockchain can be used to create self-executing contracts with established circumstances that can automate transactions and agreements in the WEF Nexus. Smart water meters, for example, when connected to the blockchain, can correctly measure water consumption and automatically execute payments or fines depending on specified criteria. This encourages water conservation behaviours and ensures the effective distribution of water resources [34]. highlights how smart contracts may increase efficiency and save money in various sectors.
3. Blockchain-Based Trading Systems**:** These systems can enable peer-to-peer trading of surplus energy or food output among farmers, consumers, and enterprises. These platforms allow for direct transactions without middlemen, reducing transaction costs and promoting resource efficiency [70]. emphasises blockchain's ability to democratise market access and benefit small-scale producers.

Blockchain technology can potentially transform the management of WEF resources in South Africa by improving transparency, efficiency, and sustainability as shown in. The government can address fundamental concerns in water, energy, and food security by leveraging blockchain's decentralised and transparent nature. South Africa can use blockchain's revolutionary power to develop a resilient and equitable WEF Nexus ecosystem that benefits its population through strategic collaborations, capacity-building initiatives, and regulatory changes.

4. Conclusion

The article highlights the interconnectedness of sustainable development, resource management, sustainability challenges, and resilience strategies in the WEF Nexus in South Africa. The study also identifies critical research gaps in addressing socio-economic dimensions, policy and governance aspects, technological innovation, and human resource development within the WEF Nexus framework. The article reveals the transformative potential of blockchain technology in revolutionising resource management in South Africa. By leveraging blockchain's decentralised and transparent nature, the country can enhance efficiency, transparency, and sustainability in resource allocation and distribution.

5. Recommendations

To operationalise the WEF Nexus and maximise the research output as depicted by the thematic clusters, the government, policymakers, and researchers should.

1. invest in capacity-building initiatives to bolster human resources' education, skills, and overall capabilities in the Water-Energy-Food (WEF) Nexus. There should be a concerted effort towards training and capacity-building programs to promote innovation, incorporating cutting-edge technologies, and adhering to optimal resource management practices amongst stakeholders and citizens.
2. embrace 4IR technology, such as blockchain, as a transparent and effective resource management instrument. Policymakers should investigate potential avenues for incorporating blockchain technologies into established WEF management systems, focusing on decentralised record-keeping, peer-to-peer trading platforms, smart contracts, and other relevant domains.

Ethics approval and consent to participate

Review and/or approval by an ethics committee was not needed for this study because the study involves the analysis of existing published data and does not directly involve human subjects or their personal data.

Informed consent

Informed consent was not required for this study because the study did not involve the use of personal or sensitive information about individuals.

Availability of data and material

Available on Request.

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CRediT authorship contribution statement

Oluwadamilola Esan: Methodology, Formal analysis, Conceptualization. **Nnamdi Nwulu:** Supervision, Project administration. **Omoseni Oyindamola Adepoju:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no competing interests.

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Not applicable.

List of Abbreviations

WEF Water-energy-food

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e37651.

References

[1] L.O. David, O. Adepoju, N. Nwulu, C. Aigbavboa, Determining the impact of economic indicators on water, energy and food nexus for sustainable resource security, Clean Technol. Environ. Policy 1 (2023) 1–18, https://doi.org/10.1007/S10098-023-02651-8/TABLES/6.
[2] Lalawmpuii, P.K. Rai, Role of water-energy-food nexus in environmental management and climate action, Energy Nexus 11 (2023) 100230, https://doi.org/10.1016/J.NEXUS.2023.100230.
[3] H. Hussein, F. Ezbakhe, The water–employment–migration nexus: buzzword or useful framework? Dev. Pol. Rev. 41 (3) (2023) e12676 https://doi.org/10.1111/DPR.12676.
[4] J.A. Allan, Virtual water: a strategic resource global solutions to regional deficits, Ground Water 36 (4) (1998) 545–546, https://doi.org/10.1111/J.1745-6584.1998.TB02825.X.
[5] P.H. Gleick, Water and energy, Annu. Rev. Energy Environ. 19 (1) (1994) 267–299, https://doi.org/10.1146/ANNUREV.EG.19.110194.001411.
[6] A. Molajou, A. Afshar, M. Khosravi, E. Soleimanian, M. Vahabzadeh, H.A. Variani, A new paradigm of water, food, and energy nexus, Environ. Sci. Pollut. Control Ser. 30 (49) (2023) 107487–107497, https://doi.org/10.1007/S11356-021-13034-1/FIGURES/4.
[7] A.K. Shams, N.S. Muhammad, Toward sustainable water resources management: critical assessment on the implementation of integrated water resources management and water–energy–food nexus in Afghanistan, Water Pol. 24 (1) (2022) 1–18, https://doi.org/10.2166/WP.2021.072.
[8] K. Nagata, I. Shoji, T. Arima, T. Otsuka, K. Kato, M. Matsubayashi, M. Omura, Practicality of integrated water resources management (IWRM) in different contexts, Int. J. Water Resour. Dev. 38 (5) (2022) 897–919, https://doi.org/10.1080/07900627.2021.1921709.
[9] A. Afshar, E. Soleimanian, H. Akbari Variani, M. Vahabzadeh, A. Molajou, The conceptual framework to determine interrelations and interactions for holistic Water, Energy, and Food Nexus, Environ. Dev. Sustain. 24 (8) (2022) 10119–10140, https://doi.org/10.1007/S10668-021-01858-3/TABLES/6.
[10] M. Vahabzadeh, A. Afshar, A. Molajou, Framing a novel holistic energy subsystem structure for water-energy-food nexus based on existing literature (basic concepts), Scientific Reports 2023 13 (1) (2023) 1–21, https://doi.org/10.1038/s41598-023-33385-8, 13(1.
[11] A. Purwanto, J. Sušnik, F.X. Suryadi, C. de Fraiture, Water-energy-food nexus: critical review, practical applications, and prospects for future research, Sustainability 13 (4) (2021) 1919, https://doi.org/10.3390/SU13041919.
[12] H.P. Huntington, J.I. Schmidt, P.A. Loring, E. Whitney, S. Aggarwal, A.G. Byrd, S. Dev, A.D. Dotson, D. Huang, B. Johnson, J. Karenzi, H.J.F. Penn, A.A. Salmon, D.J. Sambor, W.E. Schnabel, R.W. Wies, M. Wilber, Applying the food–energy–water nexus concept at the local scale, Nat. Sustain. 4 (8) (2021) 672–679, https://doi.org/10.1038/s41893-021-00719-1.
[13] A.P. Clasen, F. Agostinho, C. Teodosiu, C.M.V.B. Almeida, B.F. Giannetti, Shaping cities: a proposal for an integrative FEW nexus model, Environ. Sci. Pol. 136 (2022) 326–336, https://doi.org/10.1016/J.ENVSCI.2022.06.013.
[14] A. Lotfi, B. Mohammadi-Ivatloo, S. Asadi, Introduction to FEW nexus, Food-Energy-Water Nexus Resilience and Sustainable Development: Decision-Making Methods, Planning, and Trade-Off Analysis (2020) 29–56, https://doi.org/10.1007/978-3-030-40052-1_2/TABLES/8.
[15] I.R. Orimoloye, Water, energy and food nexus: policy relevance and challenges, Front. Sustain. Food Syst. 5 (2022) 824322, https://doi.org/10.3389/FSUFS.2021.824322/BIBTEX.
[16] M. Al-Saidi, H. Hussein, The water-energy-food nexus and COVID-19: towards a systematization of impacts and responses, Sci. Total Environ. 779 (2021), https://doi.org/10.1016/j.scitotenv.2021.146529.
[17] A. Senzanje, T. Mabhaudhi, M. Mudhara, WATER-ENERGY-FOOD NEXUS AS A SUSTAINABLE APPROACH FOR ADVANCING FOOD AND NUTRITION SECURITY AND ACHIEVING SDGS 2, 6 AND 7 WITH SPECIFIC ATTENTION TO EFFICIENT ENERGY USE FOOD PRODUCTION Report to the WATER RESEARCH COMMISSION prepared by. www.wrc.org.za, 2023.
[18] J.D.B. Gil, P. Reidsma, K. Giller, L. Todman, A. Whitmore, M. van Ittersum, Sustainable development goal 2: improved targets and indicators for agriculture and food security, Ambio 48 (7) (2019) 685–698, https://doi.org/10.1007/S13280-018-1101-4/TABLES/3.
[19] R.H. Mohtar, The WEF nexus journey, Front. Sustain. Food Syst. 6 (2022) 820305, https://doi.org/10.3389/FSUFS.2022.820305/BIBTEX.
[20] G.B. Simpson, G.P. Jewitt, The water-energy-food nexus in the anthropocene: moving from 'nexus thinking' to 'nexus action.', Curr. Opin. Environ. Sustain. 40 (2019) 117–123, https://doi.org/10.1016/J.COSUST.2019.10.007.
[21] C. Zhang, X. Chen, Y. Li, W. Ding, G. Fu, Water-energy-food nexus: concepts, questions and methodologies, J. Clean. Prod. 195 (2018) 625–639, https://doi.org/10.1016/J.JCLEPRO.2018.05.194.
[22] D.C. Moreno Vargas, C. Quiñones Hoyos, P. del, O.L. Hernández Manrique, The water-energy-food nexus in biodiversity conservation: a systematic review around sustainability transitions of agricultural systems, Heliyon 9 (7) (2023) e17016, https://doi.org/10.1016/J.HELIYON.2023.E17016.
[23] L. Nhamo, T. Mabhaudhi, S. Mpandeli, C. Dickens, C. Nhemachena, A. Senzanje, D. Naidoo, S. Liphadzi, A.T. Modi, An integrative analytical model for the water-energy-food nexus: South Africa case study, Environ. Sci. Pol. 109 (2020) 15–24, https://doi.org/10.1016/J.ENVSCI.2020.04.010.

[24] UNESCO, & European Commission, Implementing the water–energy–food–ecosystems nexus and achieving the sustainable development goals. https://unesdoc.unesco.org/ark:/48223/pf0000379588.locale=en, 2021.
[25] Z. Bian, D. Liu, A comprehensive review on types, methods and different regions related to water–energy–food nexus, Int. J. Environ. Res. Publ. Health 18 (16) (2021) 8276, https://doi.org/10.3390/IJERPH18168276, 2021.
[26] L. Sun, D. Niu, M. Yu, M. Li, X. Yang, Z. Ji, Integrated assessment of the sustainable water-energy-food nexus in China: case studies on multi-regional sustainability and multi-sectoral synergy, J. Clean. Prod. 334 (2022) 130235, https://doi.org/10.1016/J.JCLEPRO.2021.130235.
[27] S.K. Jain, A.K. Sikka, M.F. Alam, Water-energy-food-ecosystem nexus in India—a review of relevant studies, policies, and programmes, Frontiers in Water 5 (2023) 1128198, https://doi.org/10.3389/FRWA.2023.1128198/BIBTEX.
[28] D. Müller-Mahn, M. Gebreyes, J. Allouche, A. Debarry, The water-energy-food nexus beyond "technical quick fix": the case of hydro-development in the blue nile basin, Ethiopia, Frontiers in Water 4 (2022) 787589, https://doi.org/10.3389/FRWA.2022.787589/BIBTEX.
[29] L.L.B. Lazaro, R.A. Bellezoni, J.A. Puppim de Oliveira, P.R. Jacobi, L.L. Giatti, Ten years of research on the water-energy-food nexus: an analysis of topics evolution, Frontiers in Water 4 (2022) 859891, https://doi.org/10.3389/FRWA.2022.859891/BIBTEX.
[30] J.G. Segovia-Hernández, G. Contreras-Zarazúa, C. Ramírez-Márquez, Sustainable design of water–energy–food nexus: a literature review, RSC Sustainability 1 (6) (2023) 1332–1353, https://doi.org/10.1039/D3SU00110E.
[31] R. Alam, WEF: there is a way to invest profitably – and help save the world - DPI. https://www.dpi-llp.com/2021/09/23/wef-there-is-a-way-to-invest-profitably-and-help-save-the-world/, 2021, September 23.
[32] J. Terrapon-Pfaff, W. Ortiz, C. Dienst, M.C. Gröne, Energising the WEF nexus to enhance sustainable development at local level, J. Environ. Manag. 223 (2018) 409–416, https://doi.org/10.1016/J.JENVMAN.2018.06.037.
[33] O.O. Ololade, S. Esterhuyse, A.D. Levine, The water-energy-food nexus from a South African perspective, Geophys. Monogr. 229 (2017) 127–140, https://doi.org/10.1002/9781119243175.CH12.
[34] G.B. Simpson, G.P.W. Jewitt, J. Badenhorst, Development of water-energy-food nexus index and its application to South Africa and the southern african development community. www.wrc.org.za, 2020.
[35] L. Nhamo, B. Ndlela, C. Nhemachena, T. Mabhaudhi, S. Mpandeli, G. Matchaya, The water-energy-food nexus: climate risks and opportunities in southern Africa, Water 10 (5) (2018) 567, https://doi.org/10.3390/W10050567.
[36] R.K. Adom, M.D. Simatele, M. Reid, Addressing the challenges of water-energy-food nexus programme in the context of sustainable development and climate change in South Africa, Journal of Water and Climate Change 13 (7) (2022) 2761–2779, https://doi.org/10.2166/WCC.2022.099/1074240/JWC2022099.PDF.
[37] G.B. Simpson, G.P.W. Jewitt, T. Mabhaudhi, C. Taguta, J. Badenhorst, An African perspective on the Water-Energy-Food nexus, Scientific Reports 2023 13 (1) (2023) 1–13, https://doi.org/10.1038/s41598-023-43606-9, 13(1.
[38] J.O. Botai, C.M. Botai, K.P. Ncongwane, S. Mpandeli, L. Nhamo, M. Masinde, A.M. Adeola, M.G. Mengistu, H. Tazvinga, M.D. Murambadoro, S. Lottering, I. Motochi, P. Hayombe, N.N. Zwane, E.K. Wamiti, T. Mabhaudhi, A review of the water-energy-food nexus research in Africa, in: Sustainability (Switzerland), MDPI AG, 2021, pp. 1–26, https://doi.org/10.3390/su13041762, 13, Issue 4.
[39] O.M. Adeola, A. Ramoelo, B. Mantlana, O. Mokotedi, W. Silwana, P. Tsele, Review of publications on the water-energy-food nexus and climate change adaptation using bibliometric analysis: a case study of Africa, in: Sustainability (Switzerland), MDPI, 2022, https://doi.org/10.3390/su142013672, 14, Issue 20.
[40] L. Manoj Kumar, R.J. George, A. P.S, Bibliometric analysis for medical research, Indian J. Psychol. Med. 45 (3) (2023) 277, https://doi.org/10.1177/02537176221103617.
[41] J. Baas, M. Schotten, A. Plume, G. Côté, R. Karimi, Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies, Quantitative Science Studies 1 (1) (2020) 377–386, https://doi.org/10.1162/QSS_A_00019.
[42] K.R. Powell, S.R. Peterson, Coverage and quality: a comparison of Web of Science and Scopus databases for reporting faculty nursing publication metrics, Nurs. Outlook 65 (5) (2017) 572–578, https://doi.org/10.1016/J.OUTLOOK.2017.03.004.
[43] R. Pranckutė, Web of science (WoS) and Scopus: the titans of bibliographic information in today's academic world, Publications 9 (1) (2021) 12, https://doi.org/10.3390/PUBLICATIONS9010012.
[44] P. Mirzania, J.A. Gordon, N. Balta-Ozkan, R.C. Sayan, L. Marais, Barriers to powering past coal: implications for a just energy transition in South Africa, Energy Res. Social Sci. 101 (2023) 103122, https://doi.org/10.1016/J.ERSS.2023.103122.
[45] K. Cheruiyot, E. Lengaram, M. Siteleki, South Africa's energy landscape amidst the crisis: unpacking energy sources and drivers with 2022 South African census data, Sustainability 16 (2) (2024) 682, https://doi.org/10.3390/SU16020682.
[46] A. Bathaei, D. Štreimikienė, Renewable energy and sustainable agriculture: review of indicators, Sustainability 15 (19) (2023) 14307, https://doi.org/10.3390/SU151914307.
[47] M.M. Khine, U. Langkulsen, The implications of climate change on health among vulnerable populations in South Africa: a systematic review, Int. J. Environ. Res. Publ. Health 20 (4) (2023) 3425, https://doi.org/10.3390/IJERPH20043425/S1.
[48] R. Nenguda, M.C. Scholes, Appreciating the resilience and stability found in heterogeneity: a South African perspective on urban household food security, Front. Sustain. Food Syst. 6 (2022) 721849, https://doi.org/10.3389/FSUFS.2022.721849/BIBTEX.
[49] A. Molajou, P. Pouladi, A. Afshar, Incorporating social system into water-food-energy nexus, Water Resour. Manag. 35 (13) (2021) 4561–4580, https://doi.org/10.1007/S11269-021-02967-4/FIGURES/6.
[50] P. Pouladi, A. Afshar, M.H. Afshar, A. Molajou, H. Farahmand, Agent-based socio-hydrological modeling for restoration of Urmia Lake: application of theory of planned behavior, J. Hydrol. 576 (2019) 736–748, https://doi.org/10.1016/J.JHYDROL.2019.06.080.
[51] D. Naidoo, L. Nhamo, S. Mpandeli, N. Sobratee, A. Senzanje, S. Liphadzi, R. Slotow, M. Jacobson, A.T. Modi, T. Mabhaudhi, Operationalising the water-energy-food nexus through the theory of change, Renewable Sustainable Energy Rev. 149 (2021) 111416, https://doi.org/10.1016/J.RSER.2021.111416.
[52] G.B. Simpson, G.P.W. Jewitt, The development of the water-energy-food nexus as a framework for achieving resource security: a review, Front. Environ. Sci. 7 (FEB) (2019) 422789, https://doi.org/10.3389/FENVS.2019.00008/BIBTEX.
[53] L.O. David, O.O. Adepoju, Assessing theoretical frameworks, human resources management implications and emerging technologies on the water, energy and food (WEF) nexus, Journal of Digital Food, Energy & Water Systems 2 (2) (2021) 77–120, https://doi.org/10.36615/DIGITALFOODENERGYWATERSYSTEMS.V2I2.1025.
[54] S.S. Mutanga, B.K. Mantlana, S. Mudavanhu, M.S. Muthige, F.V. Skhosana, T. Lumsden, S. Naidoo, T. Thambiran, J. John, Implementation of water energy food-health nexus in a climate constrained world: a review for South Africa, in: Frontiers in Environmental Science, Frontiers Media SA, 2024, https://doi.org/10.3389/fenvs.2024.1307972, 12.
[55] M. Gulati, I. Jacobs, A. Jooste, D. Naidoo, S. Fakir, The water–energy–food security nexus: challenges and opportunities for food security in South Africa, Aquatic Procedia 1 (2013) 150–164, https://doi.org/10.1016/J.AQPRO.2013.07.013.
[56] L. El Youssfi, W. Doorsamy, A. Aghzar, S.I. Cherkaoui, I. Elouadi, A.G. Faundez, D.R. Salazar, Review of water energy food nexus in Africa: Morocco and South Africa as case studies, E3S Web of Conferences 183 (2020), https://doi.org/10.1051/e3sconf/202018302002.
[57] T. Mabhaudhi, South Africa. Water Research Commission, Assessing the State of the Water-Energy-Food (WEF) Nexus in South Africa : Report to the Water Research Commission, 2018.
[58] F. Casino, T.K. Dasaklis, C. Patsakis, A systematic literature review of blockchain-based applications: current status, classification and open issues, Telematics Inf. 36 (2019) 55–81, https://doi.org/10.1016/J.TELE.2018.11.006.
[59] G. Habib, S. Sharma, S. Ibrahim, I. Ahmad, S. Qureshi, M. Ishfaq, Blockchain technology: benefits, challenges, applications, and integration of blockchain technology with cloud computing, Future Internet 14 (11) (2022) 341, https://doi.org/10.3390/FI14110341, 2022, Vol. 14, Page 341.
[60] S.K. Panda, A.K. Jena, S.K. Swain, S.C. Satapathy, Blockchain technology : applications and challenges, Intelligent Systems 203 (2021) 300.
[61] S. López-Sorribes, J. Rius-Torrentó, F. Solsona-Tehàs, A bibliometric review of the evolution of blockchain technologies, Sensors 23 (6) (2023) 3167, https://doi.org/10.3390/S23063167.

[62] M. Javaid, A. Haleem, R.P. Singh, R. Suman, S. Khan, A review of Blockchain Technology applications for financial services, BenchCouncil Transactions on Benchmarks, Standards and Evaluations 2 (3) (2022) 100073, https://doi.org/10.1016/J.TBENCH.2022.100073.
[63] Y. Liu, C. Shang, Application of blockchain technology in agricultural water Rights trade management, Sustainability 14 (12) (2022) 7017, https://doi.org/10.3390/SU14127017.
[64] M. Garaus, H. Treiblmaier, The influence of blockchain-based food traceability on retailer choice: the mediating role of trust, Food Control 129 (2021) 108082, https://doi.org/10.1016/J.FOODCONT.2021.108082.
[65] M. Singh, S. Ahmed, S. Sharma, S. Singh, B. Yoon, BSEMS—a blockchain-based smart energy measurement system, Sensors 23 (19) (2023) 8086, https://doi.org/10.3390/S23198086.
[66] M. Tahir, N. Ismat, H.H. Rizvi, A. Zaffar, S.M. Nabeel Mustafa, A.A. Khan, Implementation of a smart energy meter using blockchain and Internet of Things: a step toward energy conservation, Front. Energy Res. 10 (2022) 1029113, https://doi.org/10.3389/FENRG.2022.1029113/BIBTEX.
[67] D. Budimir, A. Fernandez Hilario, M. Ali Alqarni, M. Saeed Alkatheiri, S. Hussain Chauhdary, S. Saleem, Use of blockchain-based smart contracts in logistics and supply chains, Electronics 12 (6) (2023) 1340, https://doi.org/10.3390/ELECTRONICS12061340.
[68] A.G. Gad, D.T. Mosa, L. Abualigah, A.A. Abohany, Emerging trends in blockchain technology and applications: a review and outlook, Journal of King Saud University - Computer and Information Sciences 34 (9) (2022) 6719–6742, https://doi.org/10.1016/J.JKSUCI.2022.03.007.
[69] I. Merrell, Blockchain for decentralised rural development and governance, Blockchain: Research and Applications 3 (3) (2022) 100086, https://doi.org/10.1016/J.BCRA.2022.100086.
[70] D. Mhlanga, Block chain technology for digital financial inclusion in the industry 4.0, towards sustainable development? Frontiers in Blockchain 6 (2023) 1035405 https://doi.org/10.3389/FBLOC.2023.1035405/BIBTEX.