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Review

A Review of the Water–Energy–Food Nexus Research in Africa

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Abstract: Notwithstanding the dispersed nature of the water, energy and food (WEF) nexus scholarship in the African continent, its strategic importance to the African agenda has gained widespread attention in research and planning circles. In this regard, the bibliometric science mapping and content analysis of the WEF nexus scientific publication trends, the conceptual, intellectual and social structures, as well as the inherent paradigmatic shifts in the WEF nexus body of knowledge in the African continent have been undertaken, using the nexus body of literature accessed from the Web of Science and Scopus core collection databases. The review results confirmed that, whilst the WEF nexus scholarship has expanded since 2013, there is also evidence of growth in the conceptual, intellectual and social structures of the WEF nexus in the African continent. These shifts have resulted in the emergence of hot topics (subfields) including modelling and optimization, climate variability and change, environmental ecosystem services sustainability, and sustainable development and livelihoods. The review further determined that these structures have evolved along two main perspectives of WEF nexus research development, i.e., the interdisciplinary and transdisciplinary domains. In support of the interpretation of the visual analytics of the intellectual structure and changing patterns of the WEF nexus research, the shifts in positivist, interpretivist and pragmatic paradigmatic perspectives (these are underpinned by the ontology, epistemology, and methodology and methods) are considered when explaining WEF nexus research shifts: (a) From the unconnected silo paradigms that focus on water, energy and food (security concerns) to interconnected (and sometimes interdependent or nested) linkages or systems incorporating environmental, social-economic and political drivers (also viewed as subfields) in a bid to holistically support the Sustainable Development Goals (SDGs) across the African continent; and (b) in the evaluation of the WEF nexus

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scholarship based on novel analytical approaches. We contend that whilst the theories of science change underpin this apparent expansion, the macro-economic theory will find use in explaining how the WEF nexus research agenda is negotiated and the Integrative Environmental Governance (IEG) is the duly suited governance theory to bridge the inherent disconnect between WEF nexus output and governance processes uncovered in the literature. Overall, operational challenges and opportunities of the WEF nexus abound, transitioning the WEF nexus research to practice in Africa, motivating the need to take advantage of the scholar–practitioner research underpinnings, as contemplated in the transdisciplinary research approach, which is characterised by the dual quest for new knowledge and considerations of use. Yet, there is need for more coordinated and collaborative research to achieve impact and transition from WEF nexus thinking to WEF nexus practice.

Keywords: sustainability; trade-offs; resilience; water; energy; food; synergies

1. Introduction

The nexus of water, energy and food (hereafter WEF nexus) is undoubtedly complex, yet critical, for it mediates numerous issues that humankind faces today. These three resource systems are intimately interlinked and essential to the livelihoods of mankind [1], whereby actions in one sector are likely to have reciprocal impacts on other sectors, resulting in conflicts or competition [2]. It is widely recognised at the community level, and the national, regional and even global scale that WEF supplies are under strain and will soon be stressed to their limits. In particular, projections show that the demand for water, energy, and food resources is expected to rise significantly. This scenario is compounded by pressures arising from population growth, urbanisation, socioeconomic development, and climate variability and change [3]. In sub-Saharan Africa, for example, the demand will be much more substantial as countries face the difficult task to sustainably meet the growing demand for the increasingly scarce resources [4]. Indeed, in many countries, particularly in the developing world, there is still demand and accessibility disparities, implying that millions of people lack such resources (e.g., water) [3,5]. In this regard, the impacts of climate variability and change as manifested in, e.g., the decreased rainfall reliability and increased water demand by the agriculture sector [6–8], are more pronounced in both agriculture and energy production—two industries that are key to several development agendas [9]. By the 2050s, the global energy demand is estimated to double, and water and food demand will increase by 50% with the drive to meet the needs of the anticipated 9 billion inhabitants [10].

As worldwide demand for the WEF nexus resources grows, their sustainability becomes a vital concern. It is against this background that the WEF nexus research theme is expected to play an important role, considering that climate change impacts and responses are typically cross-sectoral [9,11]. The WEF nexus framework, which came to the limelight at the World Economic Forum in 2008 [12] and was further developed during the 2011 Bonn Conference [13], improves such cross-sectoral coordination and seeks to integrate resource management in support of sustainable development [1]. To this end, the WEF nexus framework's salient feature is the appraisal of the interconnections and interdependencies among water, energy and food systems [11]. The WEF nexus advocates for a structured methodology geared towards maximising the inherent synergies while minimising the trade-offs and improving the efficiency of using the resources and internalising the socio-environmental influences across a range of contexts and scales [13,14]. Any lack of access to the inherently integrated systems constrains sustainable development and can have adverse effects on regional securities affecting the interrelated services needed to achieve human wellbeing, and preserve and strengthen livelihoods for generations to come. According to Olawuyi [15], the "*WEF nexus provides a coherent, holistic, and integrated implementation of the Sustainable Development Goals (SDGs).*" With just ten years remaining to achieve the 17 SDGs and their 169 targets, there is an urgent call for the effective and effi-

cient work towards attaining multiple SDGs and avoiding isolated silo approaches [16,17]. In this instance, the food (SDG 2), water (SDG 6) and energy (SDG 7) implementation through the WEF nexus lens becomes a priority. Notwithstanding the WEF nexus' noble contribution towards attaining the SDGs, the WEF nexus implementation is nascent given that it has mostly remained theoretical [18].

As a concept, the WEF nexus still needs to be translated from theory to practice [19]. Research has shown that its implementation of the WEF nexus framework on the ground remains a challenge due to several factors including the lack of adequate funding, skilled personnel, equipment, politics and commitment from member countries, more so in Africa [19–21]. Furthermore, the WEF nexus research scope—from the perspective of the spatial scale of implementation and assessment of implementation thereof—presents a significant barrier [21] to the realisation of the full potential of WEF nexus applications. In addition, the lack of standardised methodologies requisite for enhancing the development and application of "nexus thinking" can impede implementation [22]. In the study by Voelker et al. [23], the lack of institutional logic comes out strong as an impediment to WEF nexus implementation. In addition, access to information systems and data from various observational platforms, including satellite, in situ, models and assimilation systems, as well as socioeconomic data, can also be a barrier [20]. Furthermore, the lack of innovation may hinder the implementation of WEF nexus agendas [24,25] that allow, for example, the production of more food with less water and energy resources to help attain SDGs on poverty eradication (Goal 1), zero hunger (Goal 2), availing water to all (Goal 6) and provision of clean energy (Goal 7).

Despite these limitations, adoption of the WEF nexus is paramount for Africa where, on the one hand, natural resource scarcities and socioeconomic vulnerabilities are at a peak [26]. On the other hand, adaptation capacities are subtle due to population growth, low or declining economic growth, high poverty rates and a greater prevalence of food insecurities [27]. It is against this backdrop that adopting a well-coordinated and integrated WEF nexus methodology will undoubtedly contribute to building resilient systems, minimising duplication of activities, increasing the opportunity for resource mobilisation, harmonising interventions, and managing and attaining trade-offs to support sustainability [28].

This study provides a systematic review analysis of the WEF nexus body of research literature with a focus on the African continent. Thus, the present review aims to contribute to the advance of WEF nexus research through characterizing the intellectual and social structures, as well as the evolution of the WEF nexus research domain. In particular, the objectives of the review are: First, to conduct a systematic appraisal of the WEF nexus empirical research using bibliometric analysis in order to decipher the inherent intellectual patterns of WEF nexus research in the African continent. Specifically, the scientific mapping comprises trends, networks, keywords and thematic analyses of the intellectual performance from the WEF nexus scientific community. Second, the review undertakes a detailed content analysis and synthesis of the African-based WEF nexus body of the literature. A detailed examination of the content of the empirical studies of the WEF nexus in the African continent will help identify and situate inherent paradigmatic perspectives (these are underpinned by the ontology, epistemology, and methodology and methods) in order to support inferences of the visualized intellectual structure and the changing patterns of the WEF nexus research.

In this regard, our work makes the following empirical and theoretical contributions: First, the methodological approach we employ for WEF nexus scientific mapping contributes towards building a body of empirical evidence on the WEF nexus study domain in the African continent. Secondly, through content analysis, we broaden the previous research on the WEF nexus by positing that there have been paradigmatic shifts in the nexus thinking. We argue that empirical evidence points to the shifts in the WEF nexus research domain which are manifest along the lines of the need to solve societal problems, i.e., translate nexus thinking to operations and filling the inherent methodological knowledge gaps. The paper proceeds as follows: After the introduction, Section 2 presents the

materials and methods considered in the review; results are presented in Section 3; and the discussion and conclusion are presented in Sections 4 and 5, respectively.

2. Materials and Methods

The data analysed in this bibliometric review study were generated from diverse search topics within the WEF nexus subject matter. These search topics covered areas around the policy and decision making, governance and trade-offs, interdisciplinary analysis and transdisciplinary approaches, WEF climate, security nexus and general case studies conducted on the WEF nexus. The literature search was done using the Web of Science (WoS) and Scopus core collection databases. The literature search was restricted to journal articles on WEF nexus research in Africa, with no restrictions set for the period of review study, understanding that the WEF nexus is a newly developing field of research. The search was restricted to English written and published WEF nexus-related documents. An example of a WEF nexus search topic was set as follows, in both WoS and Scopus: "Water–energy–food nexus governance" OR "water–energy–food nexus policy" OR "water–energy–food nexus decision making" AND "Africa". A complete set of search topics used in this study is given in Table 1. The initial search produced 130 and 107 documents from WoS and Scopus, respectively. Following removal of duplicated articles, 45 documents were used for further analyses (see Appendix A). These included a wide range of document types, e.g., articles, reviews, conference papers, and chapter books, as shown in Table 2.

Table 1. Search topics used in Web of Science and Scopus to retrieve water, energy and food (WEF) nexus-related documents published in Africa.

Search Topic (First Row)	Areal Restriction (Second Row)
Water-Energy-Food Nexus	[AND] Africa
Water-energy-food security nexus	[AND] Africa
Water-energy-food climate nexus	[AND] Africa
Water-energy-food nexus governance	[AND] Africa
Water-energy-food nexus policy	[AND] Africa
Water-energy-food nexus trade-offs	[AND] Africa
Water-energy-food nexus decision making	[AND] Africa
Water-energy-food nexus interdisciplinary analysis	[AND] Africa
Water-energy-food nexus transdisciplinary approaches	[AND] Africa
Water-energy-food nexus case studies	[AND] Africa
Food-Energy-Water nexus	[AND] Africa

Table 2. Summary of WEF nexus documents analysed in the current review study.

Document Type	No. of Documents
Article	27
Conference and proceedings papers	4
Book chapter	2
Book	2
Review	10
Total	45

The data were analysed using bibliometric software, whereby different subfields were identified and analysed. These subgroups included developmental trends, citation analysis, keywords co-occurrence analysis, collaborations analysis and thematic analysis. VOSviewer was used to visualise the subgroups' output and generate network maps [29,30].

3. Results

3.1. Water–Energy–Food Nexus Research Trends

Figure 1 depicts the annual distribution of research articles published on the WEF nexus in Africa from 2013 to 2020. Research on the WEF nexus on the continent is still at the developmental stage. For instance, between 2013 and 2016, only 26% of the articles relating to the WEF nexus were published. There was a significant increase in annual scientific publications between 2017 and 2018. The year 2018 was the most productive in yearly scientific publications, reaching the top-notch of about 30% of published articles. Notable, the track record of the WEF nexus published articles began to decrease considerably in 2019, progressing to 2020, with only a 6% annual contribution. Overall, the yearly scientific publications, recorded in Africa, from 2013 to 2020, have shown a slow but notable increase, with a ~6% annual growth rate.

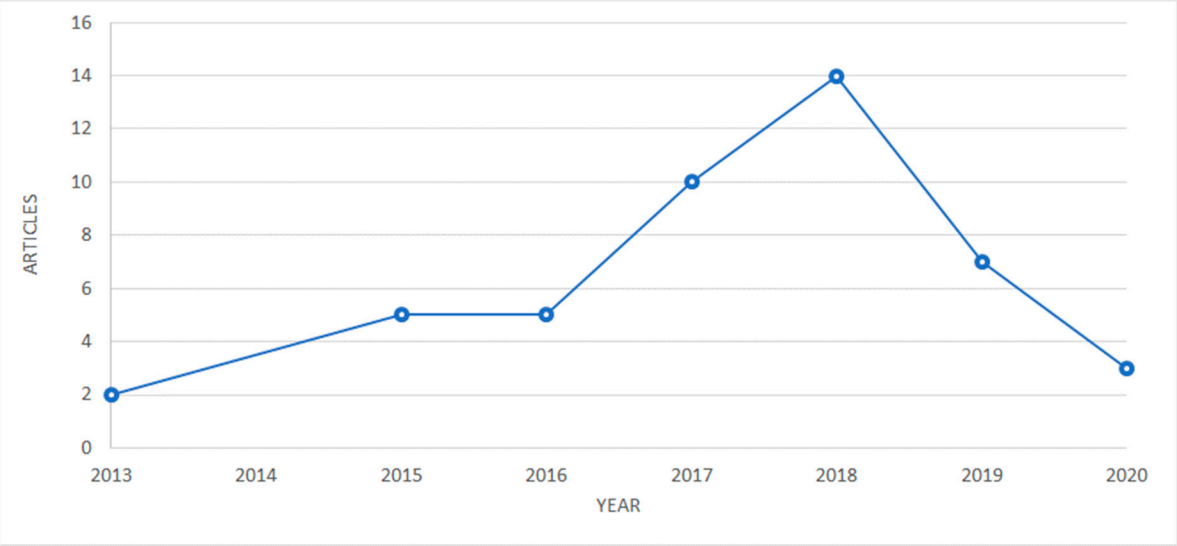

Figure 1. Distribution of annual scientific publications on water–energy–food nexus research.

Different countries on the continent have contributed towards the WEF nexus research in Africa. The first five leading countries in WEF nexus research work are shown in Figure 2. These countries are ranked based on the country affiliation of the corresponding author. Consequently, countries such as the United Kingdom, Australia, Italy and Belgium have topped the list. The United Kingdom (UK) appears to be the top leading country contributing to the advancement of WEF nexus research in Africa. In particular, the UK scholars have six published scientific articles relating to the WEF nexus, followed by South Africa with five published articles over the study period (see overall breakdown of articles in the bottom panel of Figure 2). The analysis in Figure 2 indicates that some of the published WEF nexus articles were published under Single Country Publications (SCP), whereas the others were under Multiple Country Publications (MCP). While collaborations, particularly with developing countries, are appreciated as such partnerships can boost the concrete establishment of WEF nexus research in Africa, it is worrisome that only one country, South Africa, appears in the top five list of most productive countries. However, it is worth mentioning that some of the published articles could have resulted from joint collaborative projects, with countries such as the United Kingdom and Australia were leading in the projects.

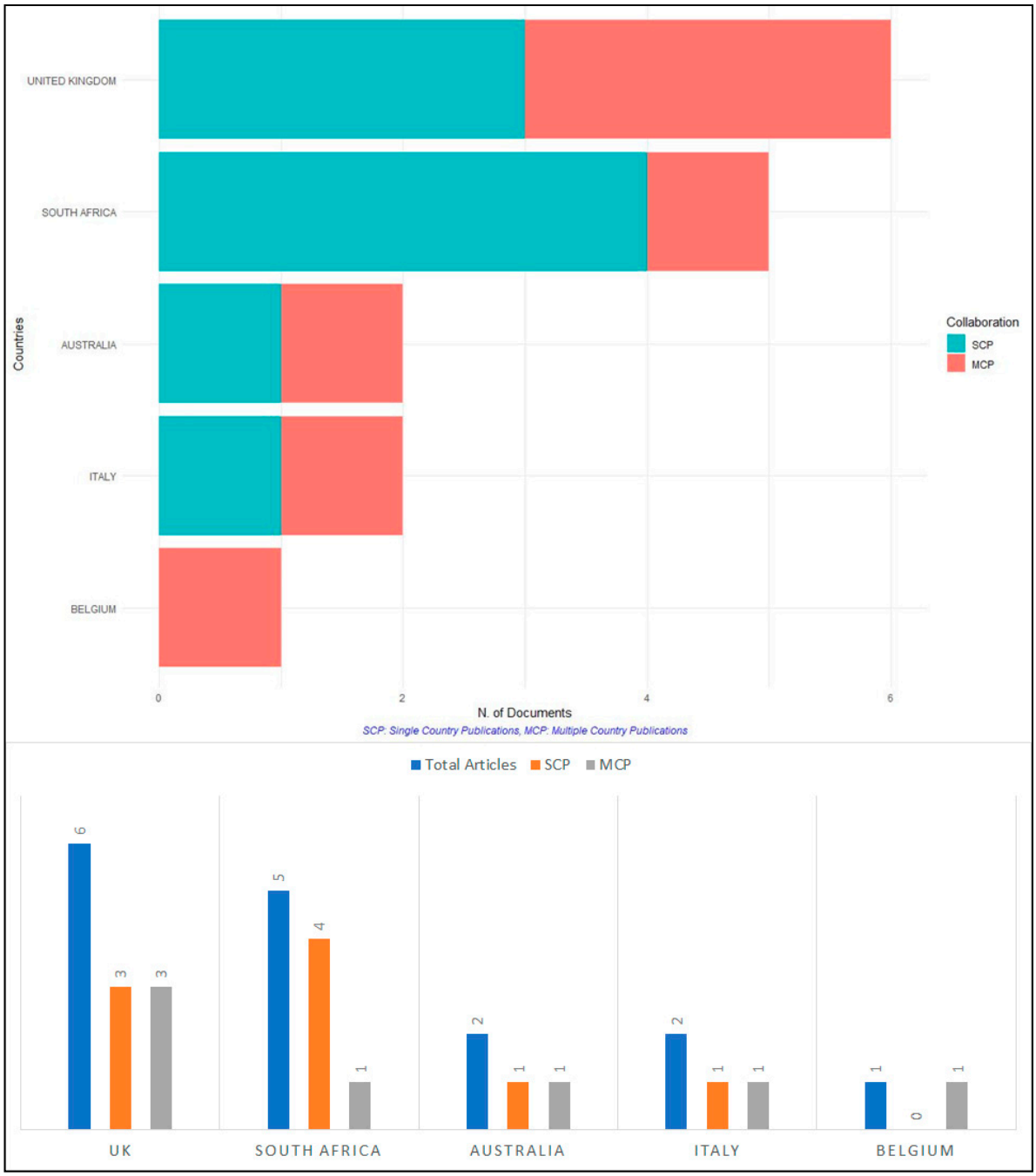

Figure 2. Top five countries that have published scientific research work on water–energy–food nexus in Africa. The ranking is based on the affiliation of the first/corresponding author's country.

The absence of articles being led by African authors should be cause for concern, given the strategic importance of the WEF nexus to the African agenda. Such absence may be due to slow uptake in emerging research themes, lack of capacity to undertake systematic research and lack of funding directed at WEF nexus research. For South Africa, the drive in WEF nexus research may be attributed to the funding policies of the Water Research Commission of South Africa who have sought to promote the WEF nexus within the country and southern African region. Greater collaboration between African authors is needed, as well as funding, in order to avoid the obvious pitfall of the WEF nexus research becoming another "western agenda for Africa". This will also help to build the necessary capacity needed to transition it from theory to practice.

3.2. Network Analysis

As shown in Figure 3, the states are assigned into different clusters, with the cluster's size depicting strong collaboration of a particular country with other countries. Most of the countries shown in the network map appear in the top five leading countries presented in Figure 3. The United Kingdom, assigned to the red cluster, depicts a strong collaboration with at least five states, including Morocco in Africa. The USA in the blue cluster represents collaborations with Australia, Italy, Belgium and South Africa. Australia in the yellow cluster has collaborated with the least countries, Kenya being the significant collaboration in Africa. Furthermore, Italy appears to be the leading collaborative country in the green cluster, collaborating with at least five countries abroad, including Niger in Africa.

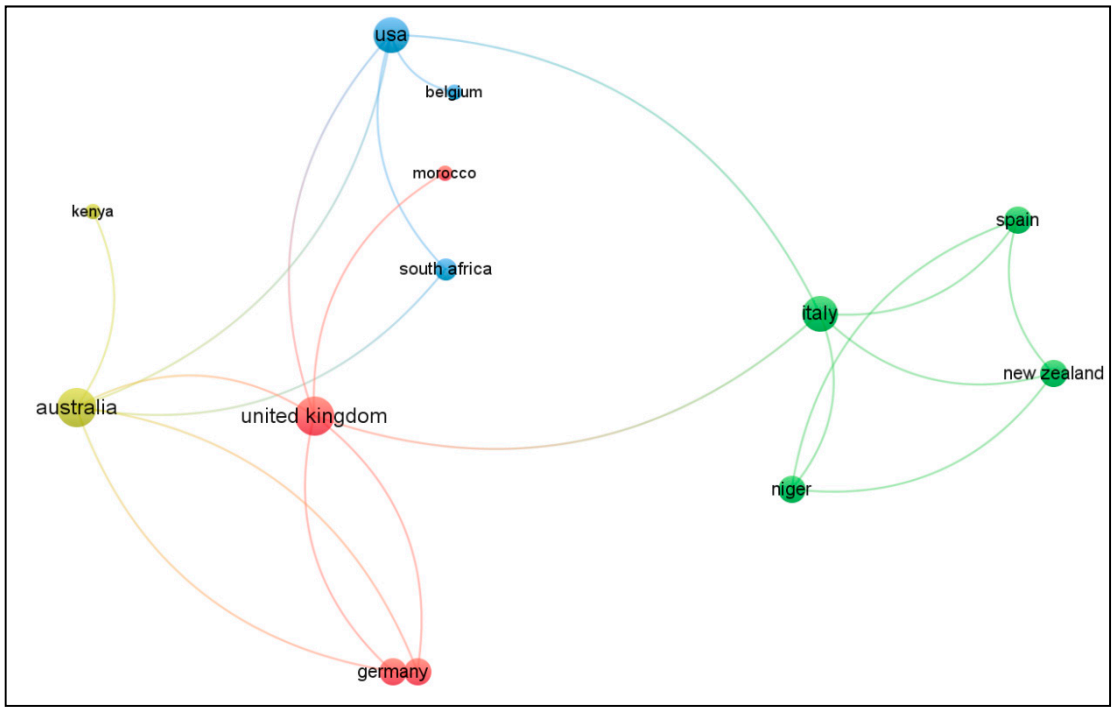

Figure 3. Countries' collaboration network, which depicts the analysis and visualisation of countries' collaboration networks.

Results for institutions' collaborations are shown in Table 3 and Figure 4. In general, the analysis resulted in five main clusters. However, only two of the clusters depict strong collaborations of institutions with and within Africa. In particular, significant collaborations in African institutions are observed in the red cluster, with the University of KwaZulu-Natal, University of Venda and Water Research Commission of South Africa, exhibiting strong collaborations among and with other South African institutions. The International Food Policy Research Institute (IFPRI), an international agricultural research centre in the teal cluster, is the central link between the blue and green clusters. Leading institutions in the green cluster are mostly found in South Africa. These include the Council for Scientific and Industrial Research (CSIR), the University of Pretoria and the University of the Witwatersrand. The international collaboration in this cluster is given by Humboldt University of Berlin and the London School of Economics. Institutions in the blue and yellow clusters have no direct links to institutions in Africa except through IFPRI. This cluster consists of two institutions in the USA, and one in China, Japan and Canada; see detailed information in Table 3.

Table 3. Clusters of institutions' collaborations in the WEF nexus research: Univ. (University); Int. (International); Inst. (Institute); CSIR (Council for Scientific and Industrial Research); USA (United State of America); UK (United Kingdom).

Cluster	No. of Keywords	Selected Keywords [Country and no. of Links Connected to the Institution]	Remarks
Red	10	Univ. of KwaZulu-Natal [SA, 10]; Univ. of Venda [SA, 8]; Water Research Commission [SA, 7]; Int. Rice Research Inst. [5]; Int. Water Management Inst. [SA, 5]; UNISA [SA, 3]; Addis Ababa Univ. [Ethiopia, 1]	Collaborations are mostly between South African institutions
Green	9	London School of Economics and Political Science [England; 9]; CSIR [SA, 6]; Humboldt-Universitt zu Berlin [Germany, 6]; Univ. of East Anglia [England; 6]; Univ. of Pretoria [SA, 6]; Univ. of Witwatersrand [SA, 6]; Univ. of Leeds [England; 3]; Sokoine Univ. of Agric. [Tanzania, 3]	Significant collaborations from Germany and England with institutions in Africa, e.g., mostly in South Africa and Tanzania
Blue	7	United Nations Univ. Inst. For Water [Canada, 7]; University of Massachusetts Amherst [USA, 7]; Xi'an University of Technology [China, 7]; Univ. de Montpellier [France, 7]	Most of the institutions have shown collaborations with the International Food Policy Research Institute in the purple cluster
Purple	5	International Food Policy Research Institute [USA, 17]; Atmospheric Sciences and Global Change Division [USA, 4]; Montana State Univ. [USA, 4]	The International Food Policy Research Institute is the key institution that has collaborated with most institutions in the green and blue cluster
Yellow	6	University in Bern [Switzerland, 5]; Oregon State Univ. [USA, 5]; Univ. of Highlands [UK, 5]	None of the institutions in this cluster have collaboration links with African institutions

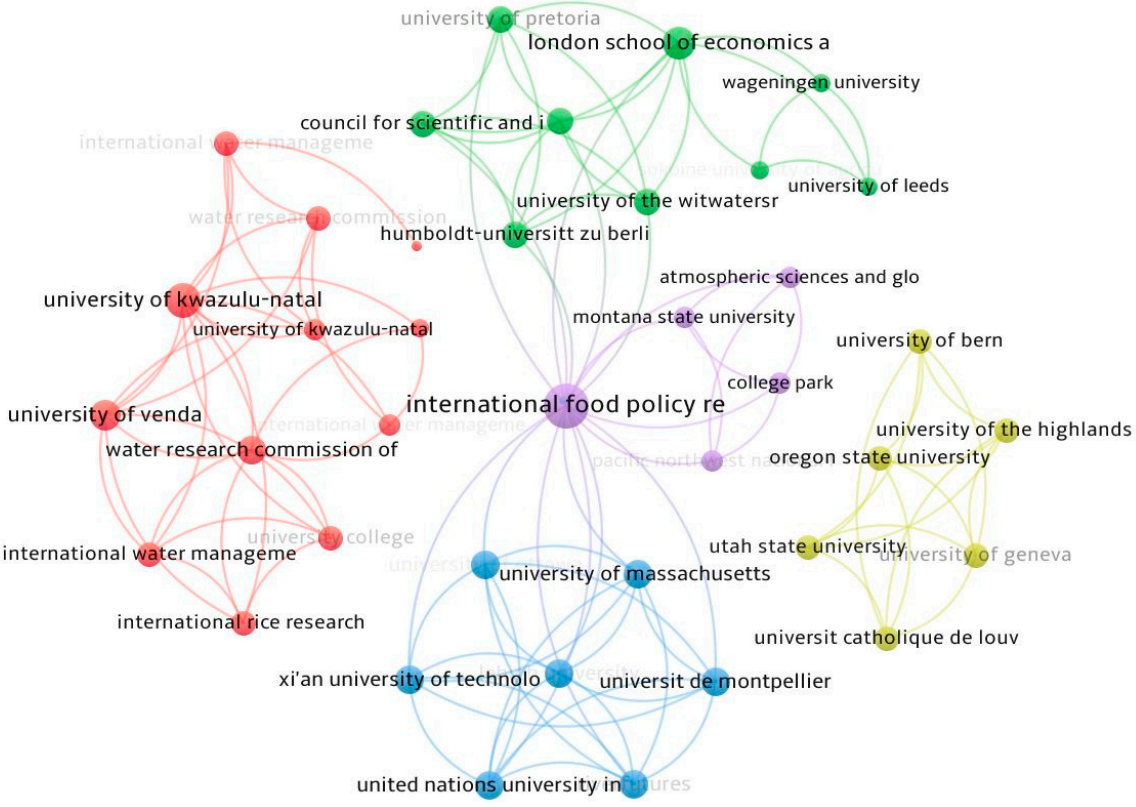

Figure 4. Institutions' collaboration network in terms of association strength of partnerships between the institutions, e.g., clusters of the same colour mostly grouped together.

Co-citation analysis was developed by Aria and Cuccurullo [31], and it maps pairs of documents that are similarly cited [32]. This tool has widely been used in the literature to discover knowledge communities [33], research fronts [34], and invisible colleges [35]. Figure 5 shows three distinct clusters of green, red and blue, denoting references with a

common intellectual base but different subfields. Consequently, each cluster illustrates the evolution of the WEF nexus' intellectual base by depicting successive research across the sub-periods(-fields).

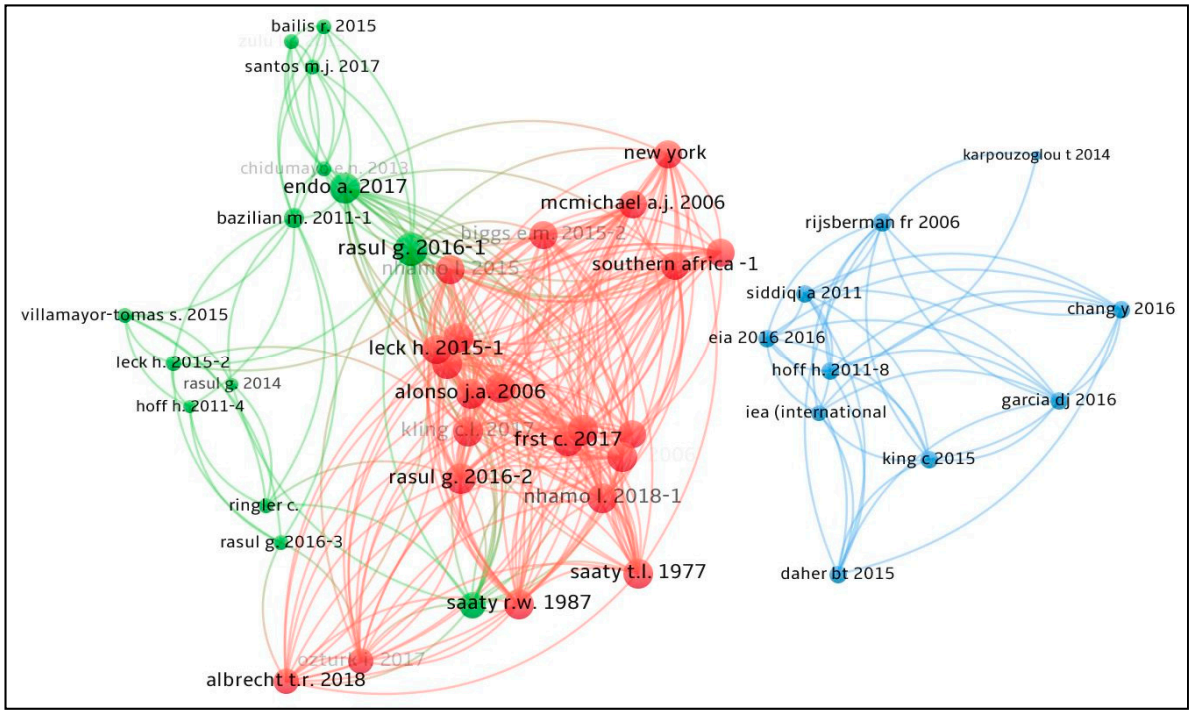

Figure 5. Authors' co-citation network based on the scientific publications on WEF nexus research, visualised by the VOSviewer tool.

The Analytical Hierarchical Process (AHP) methodology considers using the principal eigenvector underpinned by scaling ratios in order to ensure consistency in hierarchical decision-making in, e.g., WEF nexus conceptualization. In this way, the necessary weights that enable the integration of the primary (nexus resources) and secondary (e.g., other environmental drivers such as hydro-climatic extremes) components of the WEF nexus during Multi-Criteria Decision Making (MCDM) computations are optimally derived. The AHP concept has been widely utilised in WEF nexus problem solving and applied in the conceptualisation of the WEF nexus frameworks adopted by, e.g., [1,3,11,21,36–38].

For instance, the red cluster has its foundation from the research of Saaty [36], who proposed the concept of using the principal eigenvector for priorities in hierarchical structure. In this regard, the WEF nexus research work that constitutes the red cluster literature appraises the interactions between human and natural systems, cross-sectoral interlinkages, institutional arrangements, harmonisation of policies, regional integration and sustainable development, all these mediated by environmental changes under climate variability and change.

As shown in the co-citation network, the scaling ratio concept was also adopted in the green cluster by Saaty [36]. It formed one of the significant intellectual bases (third largest nodes) of the green cluster whose central theme is the consideration of environmental drivers (e.g., climate variability and change) in the WEF nexus analytical tools in so far as their role in mediating the interactions/flows of the WEF nexus primary components.

Further, the blue cluster research fronts centre on addressing challenges within the WEF Nexus, emphasising water scarcity and security from the small-scale farmers, policy implementation, resource management, efficiency, socioeconomic struggles, sustainability and climate change perspective in less developed countries across Africa. Overall, the blue cluster articles highlighted the importance of sustainable governance, integrated approaches, and cross-sectoral coordination between water–energy–food resources and

how any changes in these sectors can profoundly impact health, resilience and livelihoods of the poor.

3.3. Keyword Analysis

The keywords analysis, which represents the frequency of co-occurrence of keywords in the author's abstracts, resulted in four clusters, as shown in Figure 6. Table 4 gives detailed information of keywords in each cluster. The dominant keywords appearing in the red cluster include acclimatization, climate change, decision support system, energy, among others. In general, the red cluster hosts the largest number of keywords (a total of 21 keywords). Consequently, this cluster forms the most centralised research in WEF nexus subject-matter—related to the WEF nexus resources, climate variability and change, livelihoods and sustainable development. The red cluster comprises subfields that have drawn uttermost attention in the WEF nexus research field across the Africa continent. The green cluster contains 16 keywords, thence drawing high attention from the WEF nexus research community in Africa. Keywords with high frequency of co-occurrence in the green cluster include biodiversity, carbon dioxide, economic development and energy resource. The blue cluster has drawn moderate attention in WEF nexus research in Africa, with 13 keywords. Keywords such as agriculture, ecology economic and social effects ecosystems, energy use and food production depict a high co-occurrence frequency, suggesting the close connection with other research sub-topics within the WEF nexus research field. The yellow cluster has 10 keywords, with the most frequent co-occurrence words being crop production, decision making, food security, food supply and irrigation. While researchers have paid more attention to these keywords, the yellow cluster, in general, has attracted minimal attention in the WEF nexus research in Africa.

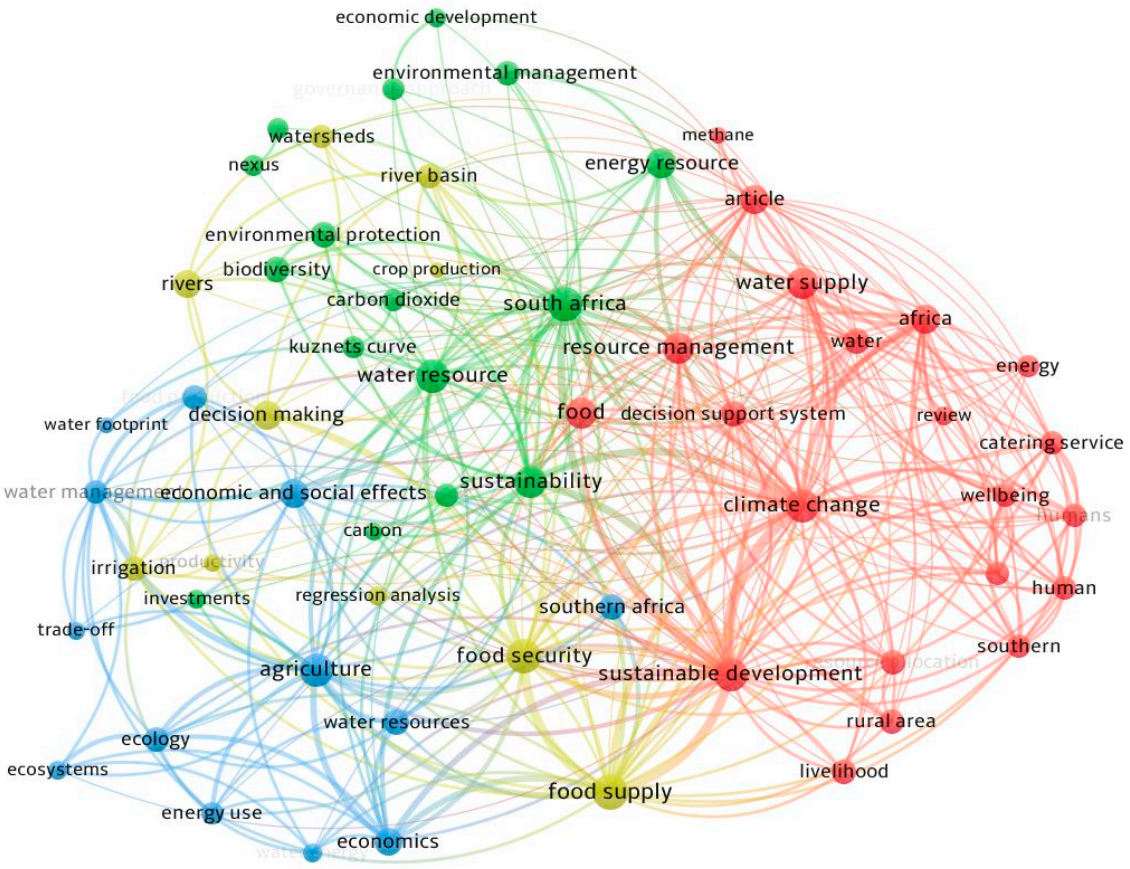

Figure 6. Keyword co-occurrences network depicting the frequent occurrence of keywords visualised using VOSviewer tool.

Table 4. Clusters of keywords co-occurrence analysis.

Cluster	No. of Keywords	Selected Keywords	Remark
Red	21	acclimatization, climate change, decision support system, energy, food, humans, livelihood resource allocation, resource management, sustainable development, water supply, wellbeing	Draws uttermost attention from researchers in WEF nexus research field
Green	16	biodiversity, energy resource, environmental management, governance approach, investments, sustainability, environmental protection, carbon dioxide, economic development	Draws high attention from researchers in WEF nexus research field
Blue	13	agriculture, ecology, economic and social effects, ecosystems, energy use, food production, trade-off, water-energy, water footprint, water management, water resources	Draws moderate attention from researchers in WEF nexus research field
Yellow	10	crop production, food security, irrigation, river basin, watersheds, decision making, productivity, food supply, rivers	Draws minimal attention from researchers in WEF nexus research field

3.4. Thematic Analysis

Themes appearing on the quadrant's upper-right corner (Figure 7) are referred to as the motor themes, and they represent strong centrality and high density [39]. Themes in this quadrant include climate change, sustainable development, water resources, and economic and social effects. These themes are considered as well developed and vital for influencing the direction of the WEF research in Africa. Themes appearing in the upper-left quadrant (e.g., water supply, regression analysis, water resources and supply) are well established but only internal; hence, such themes are marginally crucial in the WEF nexus field of research. Themes in the lower left of the quadrant include global change, land-use, mountain regions and environmental economics. These are considered weakly developed, have low density, low centrality and are either emerging or disappearing. Furthermore, themes like economic growth, carbon emissions, ecology, agriculture and water management, appearing in the lower-right quadrant of Figure 7, are essential for the WEF nexus research but still in the developing stage.

The word cloud shown in Figure 8 provides a depiction of the temporal evolution of WEF nexus research's critical themes in the Africa continent over the past decade. The temporal pattern of dominant themes depicted in Figure 8 clearly illustrates how the WEF nexus research has significantly expanded to incorporate additional thematic areas and analytics that were not in the original ontology and epistemology of the WEF nexus. In particular, at the onset, WEF nexus research in Africa was largely concerned with the security of resources, and in particular, the food resources. Therefore, the WEF nexus paradigms were premised on ontology, epistemology and methodology concerned with issues of food security. This perspective gradually shifted to include water and energy with the additional environmental (e.g., ecological, climate variability and change and the associated manifestations—hydroclimatic extremes), economic and human (e.g., population growth, urbanization) drivers. With time, the remit of the WEF nexus was mapped onto the SDGs (at global scale), and most recently, the WEF nexus challenges are increasingly being viewed using the regional, national and household lenses. These changes were/are underpinned by progress made in WEF nexus knowledge co-generation (including citizen participation—this is arguably a key bottom-up tenet of solving WEF nexus challenges) through data collection efforts and development of robust analytical modelling tools over time. These new approaches embody the transdisciplinary paradigm—a clear shift from the earlier interdisciplinary approaches of the WEF nexus research. From the review of WEF nexus literature, there is no doubt that the WEF nexus knowledge development in Africa continues to show promising growth. Thence, quantifying the

interlinkages/interdependencies of the WEF resources at scale in the African continent is expected to contribute towards scalable WEF nexus decision making, policy assessments and scenario planning. This noticeable expansion could arguably be underpinned by the theories of science change reported in, e.g., Shneider [40].

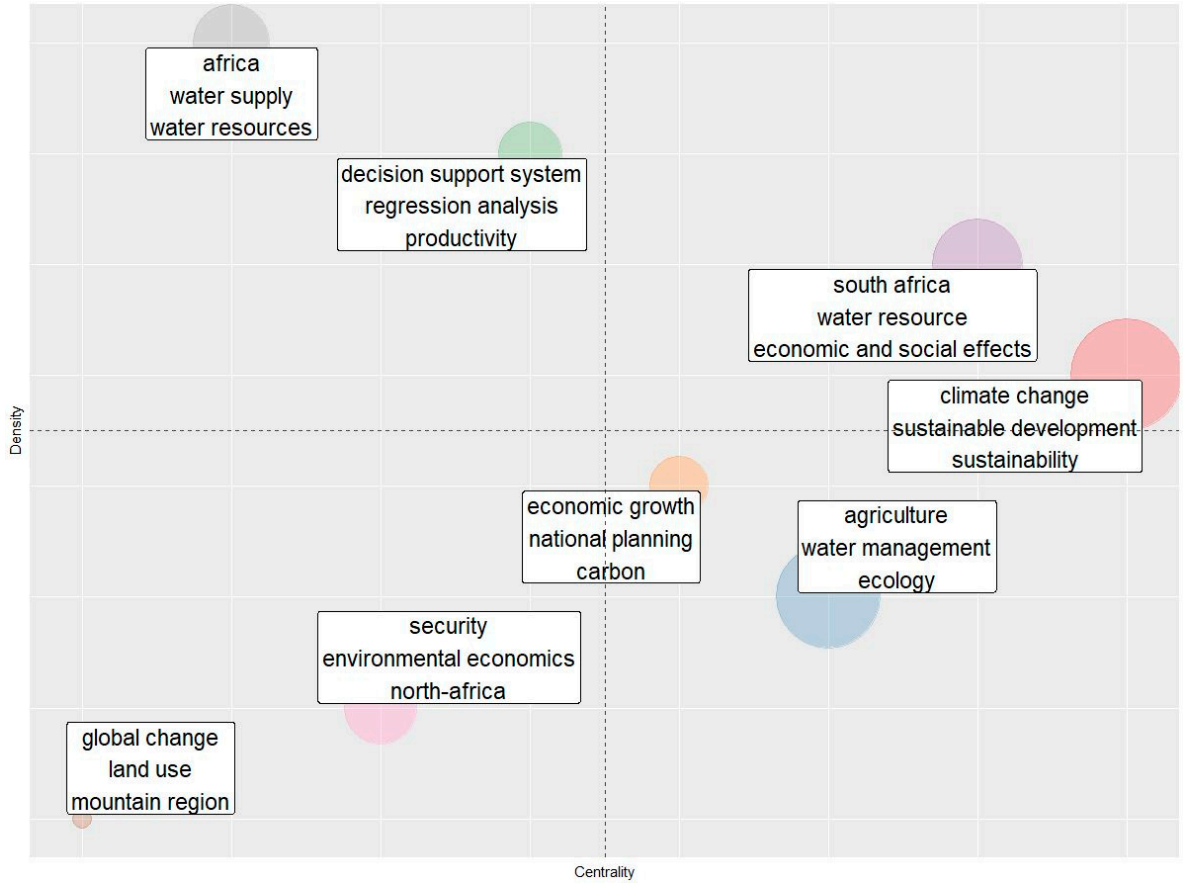

Figure 7. Thematic (strategic) map of emerging themes depicting thematic maps for the continental WEF nexus research studies.

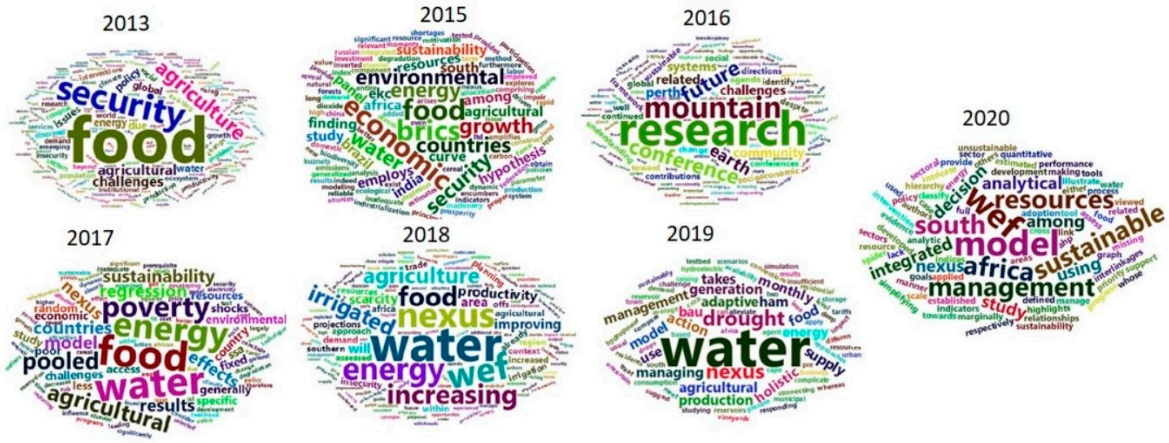

Figure 8. Temporal evolution of WEF nexus themes in the African continent.

3.5. Reflections on the Pathways of the WEF Nexus Research in AFRICA Based on Content Analysis

The scientific mapping of the WEF nexus research in the African continent presented in Sections 3.1–3.4 show empirical evidence of a growing scholar–practitioner community which is characterized by enhanced understanding of the nexus concept, the underlying challenges addressed by, and of the implementation of, the WEF nexus and the overall development of the WEF nexus methodology. In particular, the network, keyword and thematic analyses show evidence of developing conceptual (see co-occurrence analysis and thematic evolution), intellectual (see co-citation analysis) and social (see collaboration) structures of the WEF nexus in the African continent. Based on content analysis of the WEF nexus literature in Africa (summarized in Appendix A), there is evidence that these structures have evolved along two main perspectives of WEF nexus research development, i.e., (a) the interdisciplinary perspective—concerned with inherent complexity of system components linkages (including trade-off and synergies), and (b) the transdisciplinary perspective—related to the cooperation of WEF nexus scholar–practitioner community.

Furthermore, the content analysis results illustrate that there is evidence that the two perspectives of nexus thinking are premised on research that seeks to (a) develop frameworks and tools capable of characterizing the nature of the system linkages, and (b) advance policy coherence through "*optimal policy mixes and governance arrangements*" [41]. In this regard, the literature review of WEF nexus research in Africa points us to the evolution of WEF nexus research through two main pathways, i.e., filling knowledge gap and problem-solving pathways. With regard to knowledge gap filling, the reviewed WEF nexus scholarship is dispersed on whether or not the nexus methodology developed thus far is duly suited to meet the WEF nexus goals it was intended for. These debates can be situated in the positivist paradigmatic view [42] largely because the WEF nexus methodology development is abuzz with assessments, modelling (and optimization) and visualization tools that often require measurable and observable data, quantitative methods of analysis and assessment of causal relationships. On the other hand, the problem-solving pathway is manifest throughout the literature in terms of the inherent efforts to transition the nexus results (i.e., the thinking) to operations. The WEF nexus literature is rich with contextualized cases which are premised on the linkages between WEF nexus systems and the stakeholders through, e.g., participatory engagements, in order to socially construct the WEF nexus research agenda. These characteristics point to the interpretivist paradigm reported in Saunders et al. [42] wherein the WEF nexus problem is viewed from the lens of human experiences.

It is important to also take note that the reviewed literature demonstrates that the WEF nexus body of knowledge seeks to, on the one hand, study and visualize the nexus subject matter, and on the other hand, understand governance issues that relate to the social and institutional dimension of the nexus systems. In order to achieve this, empirical evidence shows that only a few of the WEF nexus projects in Africa are grounded on a transdisciplinary framework. This illustrates that the WEF nexus research methodology is slowly transcending from parallel analyses of parts of the WEF nexus problem (i.e., the interdisciplinary approaches) to an approach that involves scientific and nonscientific foundations and practice, and cooperatively (also dialoguing among different parts of society) solving complex societal problems. As evidenced from the body of reviewed literature, this pragmatic perspective is underpinned by robust stakeholder engagement (through re-enacting the WEF concept and methodology, as well as negotiations) that seeks to reposition scholars, practitioners and society as co-creators of the WEF knowledge. Overall, the WEF nexus perspectives could be cast onto various paradigms characteristic of associated tenets of the ontology, epistemology and the inherent methodology summarised in Table 5.

Table 5. Typical WEF nexus research paradigm in Africa (problem-solving vs. filling knowledge gaps): Ontology, epistemology and methodology, see e.g., [42].

Paradigm	Ontology	Epistemology	Theoretical (Conceptual Framework)	Methodology (WEF Nexus Process)	Method/Techniques	Visible in the WEF Literature Reviewed
Positivism (knowledge gap-filling)	The WEF nexus three-component sectors are viewed as real	Robust tools exist for WEF nexus that utilize the observable and measureable data	Underpinnings of the WEF nexus scholarly enterprise relate the causal relationships of sectors	WEF nexus research through experimentation, simulation, survey design	*Quantitative*: Sampling, statistical analysis and focused group interviews	Yes; more prominent in recent publications.
Constructivism/Interpretivism (problem-solving)	The scope of WEF nexus research created by individuals in groups, socially constructed through language and culture	Interpret the WEF nexus in order to uncover the underlying meaning of inter-relationships, linkages and behaviours of all stakeholders of the nexus	Use phenomenology or critical inquiry to conceptualize WEF nexus in terms of system components and the stakeholders	WEF nexus research premised on culture (ethnography), phenomenological/lived experience research on material flows within WEF nexus, transformative action research	*Qualitative*: Interviews, observation (researcher as participant/nonparticipant); case studies and narratives	Yes; more prominent in recent publications.
Pragmatism (transdisciplinary research)	WEF nexus is continuously renegotiated, debated, re-interpreted under, e.g., changing climate and pandemics (COVID-19)	The best method is one that solves the WEF optimisation problem considering the trade-offs among the resources and humankind	Research through transdisciplinary design from "*the world of human experience.*" [43]	Apply mixed methods and transformative action research	Combination of any of the above, as well as data mining, usability testing, physical prototypes	Yes; more prominent in recent publications.

4. Discussion: Salient Features of WEF Nexus Research Progression from Theory to Practice

The evolution of the WEF nexus as a scientific discipline can be viewed within the context of Shneider's theory of scientific change [40]. The analysis presented in this review shows that research on the WEF nexus has gained traction in Africa since 2013. At a global scale, the need to understand this research trajectory has been linked to the WEF resource crises in 2008 and growing concerns to move away from sector-driven management strategies [44]. The literature review points to the WEF nexus research domain transitioning through the four stages of scientific evolution, i.e., conceptualisation, the development of research tools/instruments, application of the tools to advance WEF nexus research, and accumulation of domain knowledge through scientific publications. This confirms that the research to date has been mostly theoretical. Notwithstanding the available scholarship of the WEF nexus, traditional academic research has a limited capacity for transitioning to practice. However, such transitioning to practice will entail a greater focus on socio-economic changes and human wellbeing through policies and decision-making; thus, completing the science–policy–practice interface. In order to achieve this, a more transdisciplinary research framework capable of addressing complex nexus issues is desired.

4.1. Institutional Support for the WEF Nexus Research across Africa

Since its inception, the WEF nexus research has enjoyed global, continental, regional, national and institutional support. For instance, the Southern African Development Community(SADC) region used the SADC 6th Multi-stakeholder Water Dialogue to raise awareness and create a shared understanding of the WEF nexus [45]. The subsequent workshops in SADC highlighted the knowledge gaps, stakeholders and their role at various levels required to support the nexus in meeting the water, energy and food needs of the people, and effective utilization of resources to meet the SDGs [25].

In North Africa, initiatives such as the Arab League's Nexus Dialogue Programme and the Arab Coordination Group played a crucial role in developing WEF nexus research. They informed the development of policies that address WEF challenges. In East and Central Africa, the transboundary basin of Lake Kivu and the Ruzizi River, which are shared by the Democratic Republic of the Congo (DRC), Rwanda and Burundi, is a variety of ecosystem services. Research work in the Lake Kivu and the Ruzizi River basin by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) gmbH focused on understanding the trade-offs between competing users of water, land and energy, improving natural resource efficiency to sustain human livelihoods and ecosystem integrity of the basin using the WEF nexus approach.

In West and Central Africa, the WEF nexus has been driven by institutions such as the Niger Basin Nexus Dialogue, with the role being to advise and support the Niger Basin Authority (NBA) and its member states, as well as to mainstream the WEF Nexus approach into the management of the basin. The WEF nexus has been pushed forth in the region to support integrated transboundary management of the basin and to design policies to holistically attain the development objectives by seeking efficiency of resources to address pressing developmental challenges such as food insecurity, poverty, unreliable rain and highly variable inter-and intra-annual river flows [46]. WEF-related research is still minimal in east Africa. Still, there have been initiatives by UNESCO in collaboration with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) gmbH, Strathmore University, and the Kenya Climate Innovation Centre to highlight the interdependencies between water, energy, and food in meeting global and regional goals such as the Agenda 2063 [47]. The WEF nexus is also expected to address such problems as energy-efficient production, agriculture productivity, climate change, water management practices, the impact of global oil and food prices, and the marginalisation of the poor and refugees [48].

4.2. Challenges, Opportunities and Antecedents of Transitioning WEF Nexus from Theory to Practice

Owing to the potential contribution towards the effective management of WEF resources, the WEF nexus research (this includes consideration for the inherent interdependencies and interlinkages of the intrinsic elements) has continued to gain much traction [1,49–51] to both scholars and practitioners. In this regard, the policymakers' understanding of the nexus methodology's complexity and the practical application for WEF resources management is boosted mainly by the rapid development of analysis tools and models [52]. Based on the review conducted, e.g., by Shannak [53], the practical implementation of the WEF nexus is confronted with some of the following challenges: (a) The limited number of duly suited optimised and scalable WEF nexus modelling frameworks, (b) insufficient relevant input data (at appropriate spatial-temporal scales), (c) lack of requisite knowledge and skillset required to operationalise the WEF nexus, and (d) limited application of transdisciplinary research approach that bring scholars, practitioners and society as co-creators of WEF nexus knowledge. Although the literature highlights a growing trend in Africa's WEF nexus research, the nexus concept still needs to be translated from the theoretical domain to practice [19]. Currently, the practical implementation of the WEF nexus in Africa remains a challenge due to, e.g., a lack of funding, skilled personnel, equipment and regional actors' commitment to managing transboundary resources [19–21].

An analysis of key themes above presents some of the more established and emerging nexus themes—antecedents that can support the practical application of the WEF nexus in Africa. Hot themes such as climate change, sustainable development, water resources and socio-economic livelihood are increasingly being catapult into the WEF nexus research domain. These themes' societal values are dependent on their contribution to the practical solutions derived, which integrate actors' needs and values in policy and decision-making across the affected and interested stakeholders. In this regard, coordinated and transdisciplinary efforts are needed to implement and operationalise what has been, to date, a mostly theoretical exercise. Given that there are inherent differences in concepts across the natural and social sciences, knowledge integration is often a challenging task. If not facilitated well, they will fail to co-create a shared understanding of the varied factors that modulate the social-ecological systems [54]. There is a need to formulate innovative approaches that are beneficial to the three nexus domains, and which are capable of addressing the salient features of each domain and their inherent challenges [55].

Studies by Pittock et al. [56] averred that the sectoral approaches to policy and decision-making have resulted in fragmented policy responses with limited understanding of the complex linkages between resource systems and sectors. For instance, policies that created unintended consequences have been put in place that impact sustainable livelihood [57]. In this regard, the interdependencies among the nexus components present decision-makers with synergistic problems, tensions and potential trade-offs between nexus emerging issues at spatio-temporal scales [58]. On the other hand, the established themes such as water management, agriculture and ecology provide a framework that can support the transition from theory to practice.

Opportunities that can support the transition from theory to practice include co-developing adequate resource assessment and visualization tools, expertise and institutional capacity to support the nexus dialogue. In addition, further development and application of modelling tools, technology innovation, especially during the fourth industrial revolution, encouraging broader market participation, and advanced governance to support integrated decision making [56,59] will be required. In addition, the nexus also presents opportunities to strengthen public–private partnerships and governance, as well as institutional mechanisms, to operationalise key nexus ideas. Therefore, transitioning from theory to practice in the WEF nexus requires multi-sectoral stakeholder capacity building to manage the interlinkages between resources, cost-effective policies and technological innovations. Furthermore, improving the understanding of the nexus approach through practical demonstration is key to the nexus implementation and informs planning and decision making for policymakers and other stakeholders.

4.3. Some Theories Underpinning the WEF Nexus Transition from Theory to Practice

Using the results of the scientific mapping and synthesis of the WEF nexus literature, we opine that for WEF nexus science solutions to be operationalized in the African continent, they need to take advantage of the inherent underpinnings of the science–policy–practice interface. We contend that microeconomic theory can be applied to explain how the user-inspired WEF nexus research efforts can meet societal objectives by reconciling the demand (societal need for WEF nexus knowledge) and supply (WEF nexus research). Additionally, the reviewed WEF nexus literature uncovered that there exists an inherent disconnect between WEF nexus output and governance processes. In order to respond to these governance gaps, the Integrative Environmental Governance (IEG) reported in, e.g., [60], is considered a suitable governance theory. If the societal needs are to be realised, it is natural that the scale/unit of operation of the WEF nexus ought to be framed at the local level and dynamically scaled up to macro or mega-scales. However, the WEF nexus scholarly community and practitioners are challenged to advance beyond the status quo and seek a new stand toward transdisciplinary research. This should include: (a) A reconciled demand and supply for WEF nexus scholarships informed by research agendas developed and assessed by the users, and (b) robust sensitivity analysis of how specific WEF nexus issues are prioritised under changing global environment changes.

Overall, from a philosophical viewpoint, the evolution of WEF nexus research espouses how the ontological and epistemological positions are embedded within the WEF nexus scholarly enterprise. The present review analysis illustrates evidence of shifts in the ontology-epistemology boundaries of WEF nexus research in respect of the shifts:

(a) From the unconnected silo paradigms that focus on nexus resources (security concerns) to interconnected (and sometimes interdependent or nested) linkages or systems incorporating environmental, social-economic and political drivers in a bid to holistically support the SDGs.

(b) In the evaluation of the WEF nexus scholarship based on novel analytical approaches that are (i) *innovative*—the methods are capable of quantifying and delineating WEF nexus linkages and system boundaries; (ii) *content specific*—while scalable, the methods are increasingly attuned to include multi-scalar socio-physical networks, as well as locally contextualized, (iii) *collaborative and participatory*—this enables the WEF nexus methodology to be aligned to stakeholder needs (while promoting advocacy and co-production of WEF nexus research), as well as enhancing data sharing (vital for improved model parameterization), and (iv) *supportive of the ultimate transition of research outputs to practice*, i.e., operationalizing the WEF nexus outputs.

It is against this background that for the WEF nexus research in Africa to transition from theory to practice, the philosophical positions situated in these models (ontology, epistemology, and methodology and methods) serve to be informed by transdisciplinary approaches. This clarion call requires that members of the WEF nexus scholarly and practitioner community in Africa, and elsewhere, ought to transition from the high ground of theory and descend to the swampy lowlands of practice.

5. Conclusions

In the present study, a bibliometric, as well as content, analysis of WEF nexus research in the African continent has determined the nature of the WEF nexus research structures, paradigmatic shifts, challenges and opportunities that mediate the transitioning of the WEF nexus thinking to practice. The review confirmed that the WEF nexus scholarship has expanded since 2013. This was mostly driven by the need to sustainably manage water, energy and food resources which are under pressure in the African continent. Based on the review findings regarding the nature of the WEF nexus research in the African continent, the following conclusions can be drawn:

(a) Using trends, network, keywords and thematic analyses of the accumulated collection of intellectual scientific outputs from the WEF nexus scholar–practitioner community

in the African continent, a review of the WEF nexus empirical research using bibliometric analysis shows evidence of an inherent growth in the conceptual, intellectual and social structures of the WEF nexus in the African continent. These shifts have resulted in the emergence of hot topics (subfields) including modelling and optimization, climate variability and change, environmental ecosystem services sustainability, and sustainable development and livelihoods.

(b) Based on content analysis of the WEF nexus literature in Africa, there is evidence that these structures have evolved along two main perspectives of WEF nexus research development, i.e., the interdisciplinary and transdisciplinary perspectives. In support of the interpretation of intellectual and changing structures of the WEF nexus research, it can be situated at the centre of the positivist, interpretivist and pragmatic paradigmatic perspectives (these are underpinned by the ontology, epistemology, and methodology and methods).

(c) The WEF nexus research methodology has slowly transcended from interdisciplinary approaches to those that are inclusive, i.e., the scholars, practitioners and society are co-creators of the WEF knowledge.

(d) We contend that whilst the theories of science change underpin the apparent expansion in WEF nexus scholarship, the macro-economic theory could be useful to explain how the WEF nexus research agenda is negotiated; the Integrative Environmental Governance (IEG) is the duly suited governance theory to bridge the inherent disconnect between WEF nexus output and governance processes abuzz in the literature.

(e) Operationalizing the WEF nexus research in the African continent is prone to various challenges including:

    (1) the limited number of duly suited optimised and scalable WEF nexus modelling frameworks,
    (2) insufficient relevant input data (at appropriate spatial-temporal scales),
    (3) lack of requisite knowledge and skillset required to operationalise the WEF nexus, and
    (4) limited application of transdisciplinary research approaches that bring scholars, practitioners and society as co-creators of WEF nexus knowledge.

(f) There exists opportunities for transitioning WEF nexus thinking to practice. These include co-developing adequate resource assessment and visualization tools, expertise, and institutional capacity to support the nexus dialogue.

This work contributes towards (a) building a body of empirical evidence on the WEF nexus study domain in the African continent, (b) broadening the previous research on the WEF nexus as a result of the paradigmatic shifts in the nexus thinking. These contributions are in support of the WEF nexus intent of solving societal problems under the current global changes.

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Appendix A

Table A1. Summary of WEF Nexus Scholarship in Africa.

References	Corresponding Author	Year of Publication	Country of Lead Author	Theme of the Study
[61]	Gulati M	2013	South Africa	Assesses the interlinkages of water, energy and food resources and potential influences of energy and water costs on food prices in South Africa
[62]	Hanjra MA	2013	Australia	Reviewed existing approaches, interventions and policies that support agricultural development and food security within and beyond the agriculture sector
[63]	Keulertz M	2015	USA	A study that examines five different pathways of financing green growth projects conceptualized from the WEF nexus perspective across the Arab countries using funds from regional markets and/or loans from oil-rich Gulf countries
[64]	Jobbins G	2015	UK	A summary of findings of three case studies on the bottom-up application of WEF nexus framework for drip irrigation in Morocco
[65]	Conway D	2015	UK	A study that explores the linkages between climate and water–energy–food nexus while underscoring the sectoral and spatial interdependencies that mediate policies, institutions and investments in support of security of the resources
[66]	King C	2015	UK	A study that analyzes the complex relationships between water, energy and food trade-offs and assesses rural households' green water management strategies across six basin agro-ecosystems in the Middle East and North Africa in the context of WEF nexus
[50]	Ozturk I	2015	Turkey	The study used selected ecological indicators to assess sustainability of food–energy–water resources in the BRICS countries; three indicators, e.g., food security index, cereal production and agricultural value, were constructed using principal component analysis and dynamic panel modelling
[67]	Amos CC	2016	Australia	The study underscored the role rainwater harvesting (RWH) plays in water security for individuals and governments. In particular, the study discussed the economics, quality and quantity, and WEF nexus of domestic urban and peri-urban RWH in Kenya and Australia
[68]	Gleeson EH	2016	Switzerland	Reviewed abstracts submitted to the 2015th Perth III conference, focusing on knowledge exchange, as well as establish and strengthen collaborations within mountain scientific research community; the WEF nexus is one of the future earth focal challenges that received substantial attention in this forum.
[69]	Li G	2016	China	The study used the Data Envelopment Analysis (DEA) model and city-level input-out index system derived from the interactions between the WEF nexus and population, economic and environment systems, to evaluate WEF nexus input-out efficiency.

Table A1. *Cont.*

References	Corresponding Author	Year of Publication	Country of Lead Author	Theme of the Study
[70]	Borgomeo E	2016	USA	The study proposed the use of scenarios analysis and integrated assessment modelling essential for building a sustainable future of water–energy–food resources in the Middle East and North Africa
[71]	Pieters H	2016	Belgium	The book chapter presents the assessment of interaction of water shortage, energy, and food production, by considering food security in the Kingdom of Saudi Arabia, through global perspective in a WEF nexus framework.
[51]	Ozturk I	2017	Turkey	Dynamic interlinkages between agricultural sustainability and food–energy–water poverty were assessed based on multi-techniques such as pooled least squares regression, fixed and random effects regression approaches
[7]	Endo A	2017	Japan	Provides a review and analysis of WEF nexus to assess the current status and developments
[72]	Phiri Z	2017	Zimbabwe	Provides a comprehensive review on the availability, management and sustainability of water resources in the Zambezi River Basin
[73]	Hoffmann HK	2017	Germany	The WEF nexus method was used to assess different multi-phases in Africa's charcoal value chain, thereby optimizing socio-economic and environmental outcomes
[74]	Zaman K	2017	Pakistan	A panel random effect model was utilized to assess the association between the WEF resources and air pollutions in 19 selected sub-Saharan African countries
[75]	Guta DD	2017	Ethiopia	Investigates factors that influence failures and achievements of decentralized energy outcomes in Asia, sub-Saharan Africa and South America.
[76]	Siciliano G	2017	UK	The study explored the land–water–energy–food nexus with respect to large-scale farmland investments in selected countries, with the aim to support investors and policy makers particularly on land investments
[77]	Ololade OO	2017	South Africa	The study underscores the disparities in equitable access to water, energy and food in South Africa and argues for emergent new policy paradigms and research needs requisite for sustainable development due to the interconnectedness and interdependencies of WEF resources
[78]	Urban F	2017	UK	This book presents an assessment of governance and socio-economic implications of building dams in low- and middle-income countries in Asia and Africa; the book also highlights potential benefits of infrastructure projects, particularly in promoting local and national establishments in those countries.
[79]	Adeel Z	2017	Canada	The book chapter presents aspects of regional security that includes flow of resources, sustainable economic development, alleviation of poverty, and peaceful co-existence, focusing on the WEF nexus and its role in regional security; the chapter identifies regional integration and political stability as the key ingredients for achieving regional security.

Table A1. *Cont.*

References	Corresponding Author	Year of Publication	Country of Lead Author	Theme of the Study
[80]	Zhang X	2018	USA	A review of climate change impacts on hydropower development at a global scale from the policy and WEF nexus perspectives
[81]	Udias A	2018	Italy	In the study, an E-NEXUS open software Decision Support System (DSS) was developed and applied in the Water Energy Food Ecosystem (WEFE) nexus framework across the Mékrou transboundary river basin (shared among Benin, Burkina Faso and Niger) to enhance food crop security
[21]	Nhamo L	2018	South Africa	An appraisal study status of WEF-related policies, institutions and interlinkages
[28]	Mpandeli S	2018	South Africa	A review study on climate change impacts, as well as mitigation and adaptation options, on water, energy and food resources across southern Africa
[25]	Mabhaudhi T	2018	South Africa	A review study that assessed the current status (gaps and opportunities) of irrigated Agriculture in Southern Africa based on the WEF nexus lens
[82]	Antwi-Agyei P	2018	Ghana	The study explored key themes for adaptation and mitigation within the National Determined Contributions (NDCs) of across eleven Western African States
[9]	Pardoe J	2018	UK	A case study (in Tanzania) that examined climate change policy integration and coordination across the water, energy, agriculture sectors
[83]	Yang J	2018	China	The study assessed the impacts of climate and anthropogenic changes on WEF and ecosystem sectors in the Nigel River Basin in West Africa
[84]	Dombrowsky I	2018	Germany	The study utilizes the regime theory in international relations and the benefit of sharing literature to investigate the role regional organizations such as the International River Basin Organizations (IRBOs) play in the governance of hydropower WEF nexus projects using Rusumo Falls and Ruzizi III hydropower projects in the Great Lakes region as case studies
[85]	Yang YCE	2018	USA	The study used an advanced water modelling approach and simulated the WEF nexus competition system in order to decipher the coupled human–nature interactions in the Great Ruaha River basin and used the Web-based visualization to disseminate the results to nontechnical practitioners
[86]	Mwampamba TH	2018	Mexico	The study synthesized existing literature and proposed a theoretical and conceptual framework for analyzing the interlinkages between charcoal, livestock, and hydrological processes. The proposed charcoal-livestock-water nexus is posited to have a wide range of outcomes for hydrological applications
[87]	Seeliger L	2018	South Africa	The study explores the interlinkages amongst WEF resources and also deliberates on the nexus in the context of the South African water sector, focusing on the Breede River Catchment

Table A1. *Cont.*

References	Corresponding Author	Year of Publication	Country of Lead Author	Theme of the Study
[88]	Matthews N	2018	UK	The study analyzed the challenges of building resilience and the related WEF nexus risks associated with the construction of dams using one case study each in Africa and in Asia.
[89]	Ding KJ	2019	USA	The study developed a data-driven framework for sub-Saharan African countries experiencing food–energy–water challenges; the framework employed food–energy–water resources, food–energy–water services, and food–energy–water health outcomes
[90]	Mabhaudhi T	2019	South Africa	The study assessed the rural livelihoods, health and wellbeing of the population in South Africa using a WEF nexus analytical livelihoods model from a complex systems perspective
[91]	Gush M	2019	UK	The study focused on the use of the water footprint network approach to determine water footprint information of growing crops under Mediterranean climate conditions in South Africa
[92]	Ding K	2019	USA	The study presents exploration of different methods, including an agent-based model, to manage the food–energy–water nexus in Cape Town, South Africa
[93]	Salmoral G	2019	UK	Investigated interrelationships between nexus governance and water diplomacy and their benefits for enhanced transboundary resources management, using the Zambezi River Basin as the case study
[94]	Simpson GB	2019	South Africa	Reviewed interlinkages between energy, food, and water security and their corresponding trade-offs in the Mpumalanga Province of South Africa
[95]	Hameed M	2019	USA	Reviewed current challenges related to food, energy and water security in sixteen countries in the Middle East of Africa
[96]	Siderius C	2020	England	Multi-scale analysis was used in this study to quantify the oil-dominated WEF nexus in Gulf Cooperation Council countries; based on virtual water trade, the study also assessed potential exposure to nexus stresses, including groundwater depletion in other countries, including the Middle-East and North Africa.
[97]	Nhamo L	2020	South Africa	WEF nexus sustainability indicators used to develop an analytical model for managing WEF resources
[52]	Laubscher RK	2020	South Africa	The study demonstrates an implementation of an algae-to-energy sewage treatment system in southern Africa through an operation of an Integrated Algal Pond System (IAPS). The proposed IAPS-based algae-to-energy sewage treatment provides alternative energy co-production in a peri-urban setting under a constrained WEF nexus

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