



Review

Tracing attribute and scope of research and applied projects in Africa's water energy food nexus implementation: A review

Fabien Muhirwa^{a,b,c}, Lei Shen^{a,b,d,*}, Ayman Elshkaki^{a,b,d}, Kgosietsile Velepini^e,
Hubert Hirwa^{b,f}

^a Key Laboratory for Resource Use and Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

^b University of Chinese Academy of Sciences, Beijing 100049, China

^c Department of Natural Resources and Environmental Management, Protestant Institute of Arts and Social Sciences, Huye 619, Rwanda

^d Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Natural Resources, Beijing 101149, China

^e Environmental Education Unit, Faculty of Education, University of Botswana, Gaborone 45685, Botswana

^f State Key Laboratory of Ecosystem Network Observation and Modeling, Chinese Academy of Sciences, Beijing 100101, China



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ABSTRACT

The importance of integrating water, energy, and food (WEF) resource management into nexus approach has been widely recognized. However, despite its rapid growth, there are little discussion of the knowledge transfer from nexus research to practice of WEF nexus implementation in Africa. This research examines the WEF nexus implementation baseline through critical analysis of present studies and official project reports initiated by African government institutions from 2011 to 2021. The findings indicate that numerous WEF nexus research projects in Africa focus on generating fundamental knowledge with limited practice. Indeed, among the 237 WEF-related applied projects analyzed, only 26 projects correspond to the nexus approach in three resource sectors. Many proposed projects are managed at the level of individual resource areas and are prioritized according to urgent needs or regional contexts rather than being integrated for mutual benefit. The word "production" receives a high score in the statistics of term frequency and inverse document frequency (TF-IDF), expressing that it is considered very relevant in the process of implementing the nexus approach. The results of the similarity index between the content messages of the academic articles and the project implementers' reports show a low similarity score of 0.25, indicating some imbalance in understanding and adapting nexus concepts between these two critical sectors. Hence, reflecting on the various nexus opportunities reviewed in this study, such as Bonn nexus conceptions and projects allocation, may serve as a focal point and assist WEF nexus implementers, particularly scholars, in resolving the numerous ambiguities that exists in WEF nexus research and practice.

1. Introduction

Recent reports from the Sustainable Development Goals Centre for Africa (SDGCA) show that Africa has only achieved SDG 13 on climate action and SDG 15 on life on earth, but with no hope of achieving the core goals of zero hunger, universal access to WEF resources and poverty reduction by 2030 (SDGCA et al., 2019). Studies also mention that the mismanagement of WEF resources for human subsistence will continue to inextricably link with poverty, hunger, and human health (RES4Africa, 2019a, 2020). For example, over 60 % of poor people in

the Southern African Development Community (SADC) region have limited access to water, energy, and food resources (Nhamo et al., 2018). Similar issues are common among all other regions in Africa (EAC, 2017; Martin Keulertz, 2019; Shaban, 2017). Furthermore, the 14th World Economic Forum (2019) report indicated the existing gap between food, water and energy in Africa, mainly in sub-Saharan African countries (WEF, 2019). There are numerous trade-offs in resource allocation, such as energy resources used in various food security sectors, water management, socio-economic services, and community livelihoods (Wolde et al., 2020). Simultaneously, accepting trade-offs between institutions

* Corresponding author at: Key Laboratory for Resource Use and Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.

E-mail address: shenl@igsnr.ac.cn (L. Shen).

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and policies is a complex and practical challenge toward integrating the WEF nexus philosophy into African socioeconomics (Mohtar, 2016).

In response to that, the Africa Regional Nexus Conference of the United Nations on Sustainable Development recommended the WEF nexus approach as a multi-sectoral approach that could raise awareness and harmonize the use and management of the three resources (UNCSD, 2011). The conference came after the previous concurrent World Economic Forum and Bonn Nexus conferences, at which the WEF nexus was proposed (Hoff, 2011). The African international partners, such as Renewable Energy for All in Africa (RES4Africa), also emphasized promoting the ideas of WEF nexus in transformative engagement projects as a good opportunity to improve the lives of the poor and needy, and to improve environmental sustainability (RES4Africa, 2019b; UN, 2019). Correspondingly, numerous studies have demonstrated that the WEF nexus has potential to be used as a tool for social and rural change in Africa through good governance, social equity, environmental sustainability, and sustainable development (Lee et al., 2020; Tafadzwanashe et al., 2019). As a result, the number of projects proposed, funded, and implemented under the WEF nexus philosophy has increased in Africa (RES4Africa, 2019b). However, it is difficult to determine if they are working from the nexus perspective.

The WEF nexus has many sub-components that are difficult to track in the overall policy direction of each resource sector, leading to confusion and criticism among researchers, policy makers and practitioners about each side's failure to implement the WEF nexus (Kurian et al., 2019). Many investors, policymakers, and practitioners have criticized researchers for not providing appropriate tools, knowledge, and methods to highlight and transfer the relevance of the WEF nexus approach into stakeholder practices (Guenther, 2020; Lamizana, 2020). On the other side, researchers also cited a limited willingness of policymakers and practitioners to pay the cost of synergies relative to the existing system of trade-offs dominating the management of WEF resources (Terry, 2020). The other major problem with nexus is the lack of a common platform for perceptions of the nexus approach (Endo et al., 2017). The inclusion of all stakeholders in the complexity of implementing WEF nexus approach appears to be overlooked and must be carefully evaluated. This prompted us to conduct this study to determine the extent to which stakeholders understand and value the approach, limitations, and potential for its implementation.

In recent literature, many authors have expressed interest in conducting systemic and critical analyses of WEF nexus at the national or regional level to better understand the WEF nexus approach and suggest new pathways for implementation (Dalla Fontana et al., 2021; Kondash et al., 2021). Botai et al. (2021) and colleagues reviewed 45 research papers to learn more about the history and characteristics of WEF nexus research in African countries. Despite the efforts of researchers, their findings have primarily focused on illustrating the characteristics and historical development of the nexus literature in the countries involved. The studies that analyze the type of knowledge provisioning in the WEF nexus research in Africa or elsewhere towards the practical and political demand have some analytical shortcomings. In many cases, the WEF nexus projects reported are those carried out by nexus research experts or related institutions, with few examples of how government institutions or private sectors incorporate a nexus approach into their implemented WEF resource projects, resources management and use.

This study considers three different parameters of the Bonn conference nexus conception, the provision of types of research knowledge, and the applied projects implemented by African governments within WEF resources. The first objective of study is to identify and discuss the attribution of research knowledge provision to practical needs, flaws, and criticisms of the WEF nexus approach. The second objective is to assess whether the WEF projects proposed and initiated by African government institutions contribute to the successful implementation of the WEF security nexus. The third objective is to evaluate the level of awareness and similarity of adaptation of WEF nexus among policymakers and researchers in their respective projects, targets, activities,

and outcomes. Finally, insights from the Bonn Nexus Conference on the principles and benefits of nexus design are used to assess whether the scope of WEF nexus implementation in Africa is in relation to the overall nexus core mission. The following diagram (Fig. 1) illustrates the structure of our work:

2. Methods and Materials

This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) procedure, which facilitates the identification and selection of documents from research platforms (Moher et al., 2009). The PRISMA approach was utilized to collect both peer-reviewed scholarly literature (comprising peer-reviewed papers, proceedings, and books [chapters] available in the Scopus and Web of Sciences databases) and major national water, energy, and food projects from 2011 to May 2021.

The projects were collected from the official platforms of the Global Environment Facility (GEF) (<https://www.thegef.org/who-we-are>) and the Nexus Resource Platform (<https://www.water-energy-food.org/knowledge-hub>). These two platforms were chosen because they have official data on the main ongoing global projects financed by the United Nations, international cooperation funds, and some African governments. Governmental or applied projects are projects proposed and financed in the WEF sectors, with sector benefits or sector integration, while WEF nexus projects are proposed and financed specifically for the WEF nexus objectives. Most of the projects assessed are financed by international cooperation, such as the World Bank, GEF, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the European Union, and the Stockholm Institute for the environment. The selection of time period is based on the official introduction of the WEF nexus in Bonn, Germany, in 2011. The documents were first selected based on the criterion that "water," "energy," "food," and "nexus" appeared in the title. Thus, 286 papers and 5171 projects were registered in the initial evaluation, and after sorting and deleting duplicates, 220 papers and 269 projects remained. These were assessed under the additional criterion that the term Africa, an African country, or a region of Africa was contained in the title, abstract, or list of keywords. Only 46 articles and 237 projects were taken for further analysis (Fig. 2).

The selected documents were all downloaded from relevant publishers' websites for projects, put into folders and fed into the MAXQDA software (version 20.4.0) for review and coding. MAXQDA is qualitative data analysis software used to systematically review relevant text passages in qualitative and quantitative terms. It had been developed to review, code, and analyze the documents qualitatively and quantitatively (Oliveira et al., 2013). Our coding scheme is generally subject to the content of the knowledge provision in each research type (Brown, 2015; Eden and Huxham, 1996; Svensson et al., 2007). Other coding elements were taken from the WEF nexus conception principles of the Bonn nexus conference (Hoff, 2011).

In this study, research coding focused on the original author's primary findings rather than generalizing entire article texts. The same priorities were established for national projects to focus more on objectives, activities, and outcomes mentioned along with the project's implementations. Two types of coding systems are used: automatic coding accounts for the frequency and nuanced words in the selected documents' code items, while manual coding is used to read the entire document or target part and categorize similar content chunks (codes) within the software. Along with the MAXQDA analysis tool, the RapidMiner tool is also used to perform statistical analysis from qualitative data to quantitative insights to illustrate the baseline and profile the WEF nexus's implementation in Africa. Within RapidMiner, term frequency-inverse document frequency (TF-IDF), a statistic that can be used to determine significance of a word in a collection of documents with a focus on how common or rare a word is in the entire document set, is calculated (Paik, 2013; RapidMiner, 2021). This TF-IDF calculation is accomplished by multiplying two metrics: the number of times a

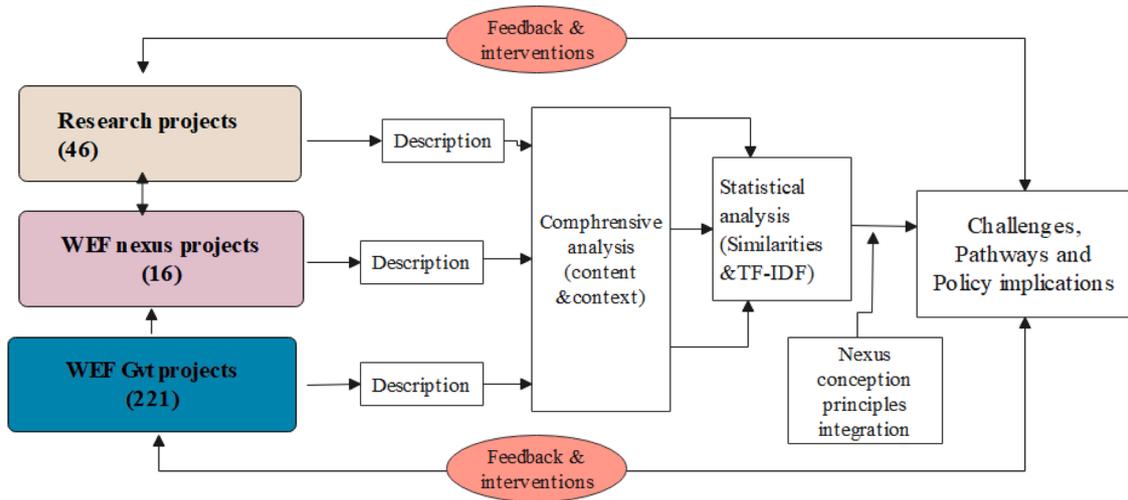


Fig. 1. Schematic figure of work structure, (Gvt=Government).

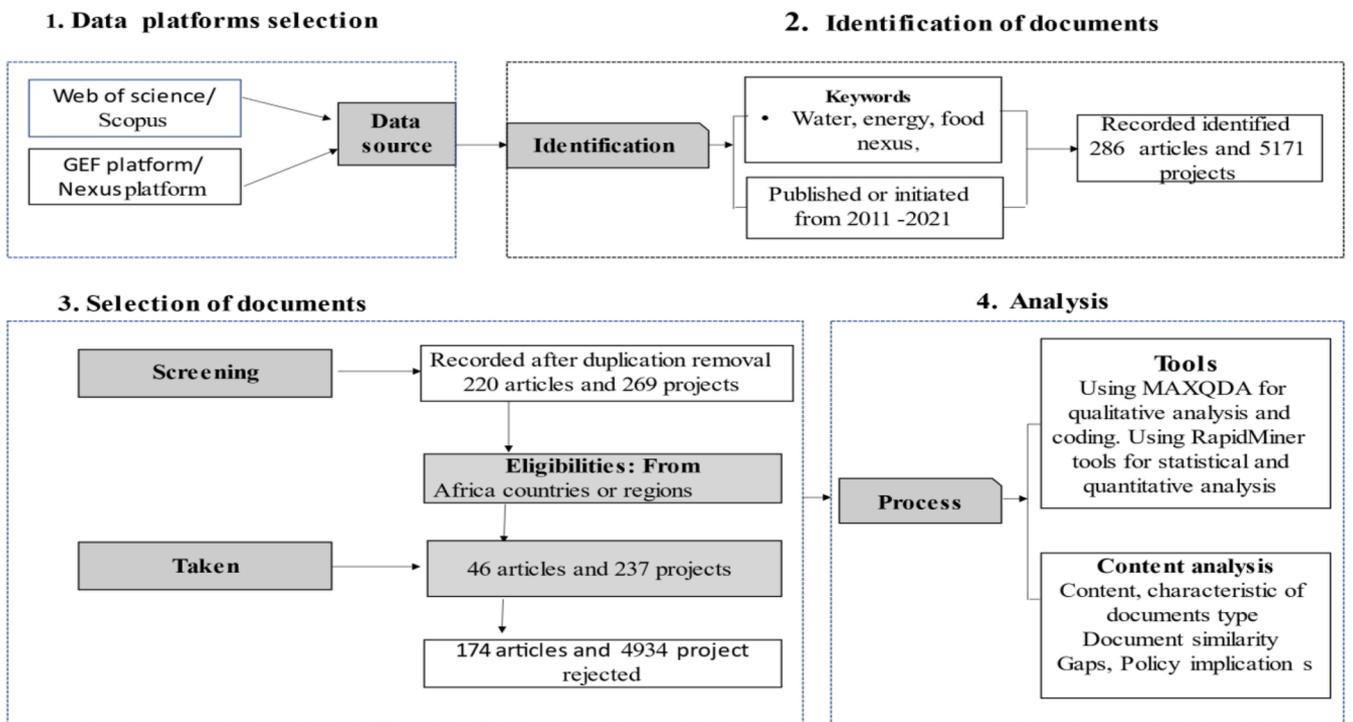


Fig. 2. Flowchart of the methodological development.

word occurs in a document and the word’s inverse document frequency over a collection of documents via the following equations:

$$TF - IDF(n, d, C) = tf(n, d) \times idf(n, C) \tag{1}$$

where

$$tf(n, d) = \log(1 + f(n, d)) \tag{2}$$

and

$$idf(n, C) = \log\left(\frac{N}{Count(d \in D : n \in d)}\right) \tag{3}$$

In these formulas, the TF-IDF value for the term *n* in text *d* from the corpus set *C* is calculated, *tf* denotes as total frequency, *idf* is inverse document frequency, and *N* is the total number of documents. The words

of a document that score the highest TF-IDF value are interpreted to be the most relevant to that document.

In addition, the cosine similarity is calculated to determine the extent to which the research in the WEF Nexus and WEF Projects reports similarly through their content. This was done through the Cross Distances operator in RapidMiner, which takes two example sets as input, i. e., the "reference set" and the "request set." The reference set has taken the form of sentences that contain words expressing the integration of three resources: "nexus," "integration," and "collaborative targets." The input request set is prepared by combining all articles of nexus research into excel file, namely "nexus research," and also putting together all projects related to nexus into the second file, namely "nexus project," and the same for the third type of WEF resource projects put together into a third excel file, then running autogenerated RapidMiner tools analysis. All data are processed by converting all words into lowercase,

removing punctuation, removing stop words, and lemmatization/stemming, which is critical to minimizing errors caused by counting irrelevant words (RapidMiner, 2021).

3. Results

3.1. Research and projects descriptions

In evaluating WEF security nexus from research to practice in Africa, 283 documents were analyzed, split into 46 research papers and 237 national project reports published officially on water, energy, and food resources across the African continent. The findings show that research and policy on WEF nexus were implemented later in Africa. For example, the data shows that no scholarly papers on the African WEF resource nexus were published on the Web of Science or Scopus in 2011 and 2012. Along with the WEF nexus research development, South African scholars have contributed more to nexus research co-authorship in general, whereas British, American, Dutch, and German authors predominate among overseas authors (Fig. 3).

Further results (Fig. 4) present a typology of frequent words appearing in all documents corpus; “water” is the most frequent (342 times), followed by “energy” (330), “nexus” (264), “practice” (258), “food” (250), “production” (242), “land” (231), “policy support” (221), “management” (219), “resources use” (210) and others. In addition, the results indicate that “water”, “energy”, and “resource use” were more specific topics and interest in the research papers. Similarly, “water”, “nexus”, and “energy” appeared more frequently WEF nexus projects, while in applied projects, “water”, “management”, and “climate change” are more prevalent Table 1.



Fig. 4. The top words in the document corpus. Source: elaborated by the authors.

3.2. Comprehensive review on research publication type

In expanding the WEF nexus studies in Africa, Table 2 illustrates the context of WEF nexus research with its types and knowledge generation for community practitioners. This uses thematic content analysis to explore where nexus research provides more relevant knowledge in the implementation process. Classifying different types of research helps to

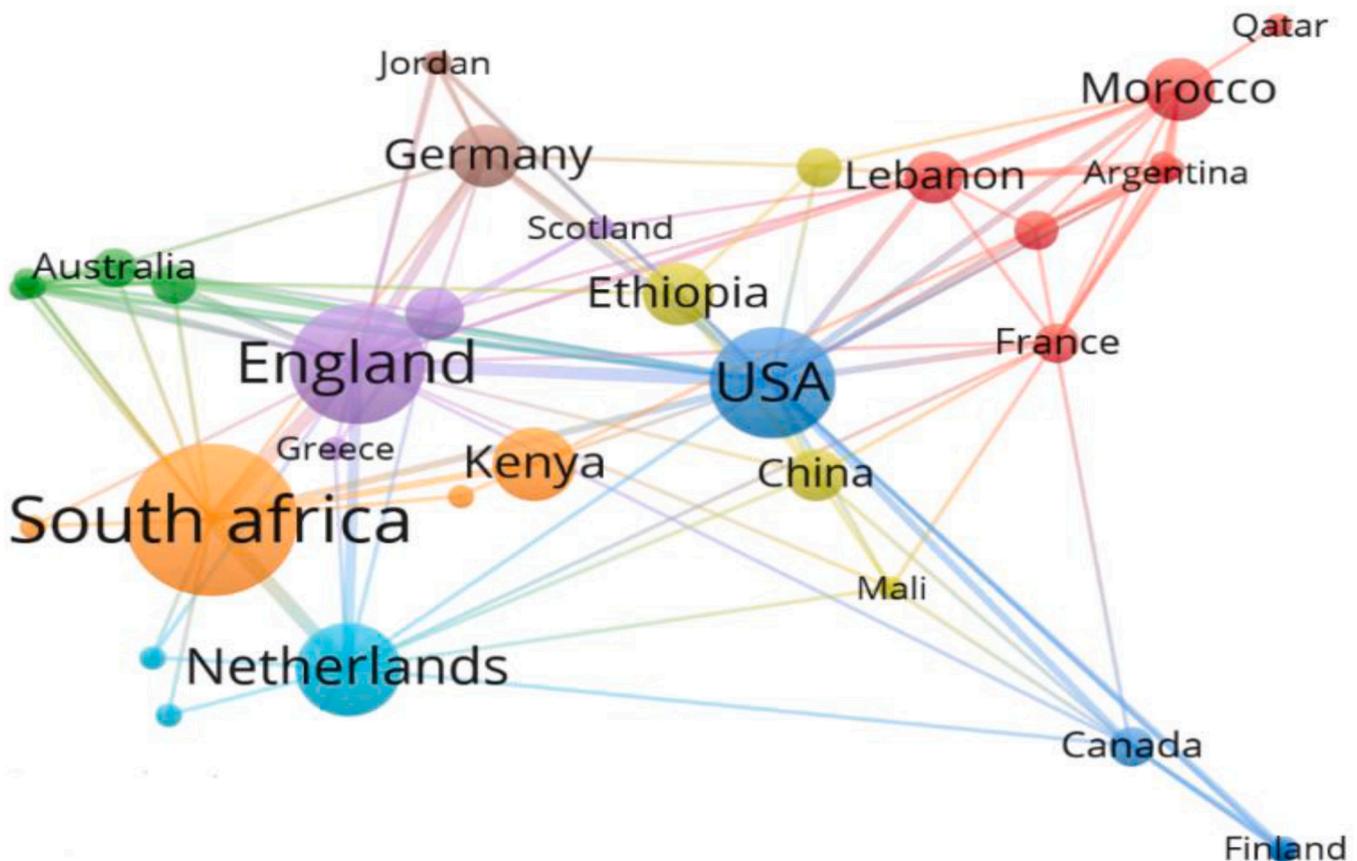


Fig. 3. : Nexus research co-authorship by country or region. Elaborated by the authors using VOS viewer software.

Table 1
Documents coding scheme.

Code	Elements of Coding	Reading papers	Coding system
Research knowledge context provisioning	Action, Applied, Evaluation, or Basic	Topic, Introductory part, methodology and findings	Manual
Similarities and TF-IDF (Bonn nexus conception)	Nexus, integration, collaborations words for similarities and nexus conceptions benefits for TF-IDF	Topic, objectives, activities and outcomes for projects Full reading for research papers	Automatic & manual
The nexus conception principles (Bonn nexus conception)	Resource Productivity, capacity building, Ecosystem benefits, Poverty reduction, governance and policy coherence, Economic incentive, waste resource management	Topic, objectives, activities and outcomes for projects Full reading for research papers	Automatic & manual

evaluate knowledge developments, examine controversies among scholars, and identify gaps in research areas (Gabel, 1993).

Generally, the research category’s description should reflect different criteria such as the discipline, field of study, type of knowledge generation, data available, methodology, time frame, and study field (Vergne and Wry, 2014). In this study, we base our analysis on a criterion of the type of knowledge generation summarized in Table 2. The action research is sometimes considered part of the applied sciences (Eden and Huxham, 1996; Svensson et al., 2007). Similarly, some studies consider evaluation research to be part of the applied sciences (Brown, 2015). Without disputing these existing practices but expanding the philosophical nature of WEF nexus studies in Africa, our study classifies these types based on the interpretations summarized in Table 2.

Sources used for research classifications: basic research (Fisher and Mazur, 1997; Schauz, 2014; Toole, 2012), applied research (Brown, 2015; Fisher and Mazur, 1997), evaluation research (Brown, 2015; Pries-Heje et al., 2008), action research (Cohen et al., 2017; Elg et al., 2020).

In the categorization of research intention and criteria in Table 2, 16 scholarly articles are reported to provide foundational knowledge about the nexus approach, particularly on the definition of the term "nexus," and its various adaptations in different contexts highlighting its overall benefits with the SDGs. Scholars also provide a key picture of the challenges and opportunities for adapting nexus for the mutual benefit of stakeholders. For example a study by Botai et al. (2021) on understanding WEF nexus research in Africa recommended a transdisciplinary strategy characterized by the concurrent exploration of continuous learning and consideration of practice knowledge. Bromwich (2015) highlighted the linkage between conflicts and WEF nexus-related challenges in Africa’s conflict zones. Chirisa and Bandauko (2015) further illustrated the importance of linking WEF nexus with sustainable cities in Africa.

Furthermore, 15 articles showed a central focus on applied research to provide socio-economic and environmental techniques, tools, and models for specific resource integration, structural transformation, and governance. These articles include a study by El Gafy et al. (2017a), which show the implicit irrigation systems approach to support agricultural production from the perspective of the WEF nexus. Resource management optimization, climate change assessment and modeling, resource allocation, and hypothesis testing are among highlighted applied areas of research to provide alternative solutions to the same challenges of nexus implication in Africa (Dombrowsky and Hensengerth, 2018; Ogbolumani and Nwulu, 2021).

Evaluation knowledge is one of the insights that research should

Table 2
Intended purpose of research of WEF nexus studies on Africa.

Studies category	Intention & criteria	Number of articles	Authors & References
Basic Research	<i>Use related WEF nexus research to:</i> 1. Generate basic knowledge (on WEF nexus). 2. Improve scientific theories for better comprehension, without concerns of applicability and more internal validity	16	(Botai et al., 2021), (El Youssfi et al., 2020) (Chirisa and Bandauko, 2015) (Hoffmann et al., 2017) (Ololade et al., 2017) (Gulati et al., 2013) (Khacheba et al., 2018) (Nhamo et al., 2018). (Megerle and Niragira, 2020) (Simpson and Jewitt, 2019) (Mguni et al., 2020) (Simpson and Jewitt, 2019) (Mpandeli et al., 2018) (Wolde et al., 2020) (Elagib et al., 2021) (Bromwich, 2015) (Wong and Pecora, 2015)
Applied Research	<i>Use related WEF nexus research to:</i> 1. Focus on testing a hypothesis that gives an alternative solution to variable challenges and needs. 2. Deal with improving process and knowledge of management and production among resources.	15	(Ogbolumani and Nwulu, 2021) (Okola et al., 2019) (Borgomeo et al., 2018) (Dombrowsky and Hensengerth, 2018) (Bazzana et al., 2021) (Elsayed et al., 2020) (Martins, 2018) (Simpson et al., 2019) (Stein et al., 2018) (Wolde et al., 2021) (Imasiku and Ntagwirumugara, 2020) (Yang et al., 2018) (El Gafy et al., 2017a) (Johnson and Karlberg, 2017) (King and Jaafar, 2015).
Evaluation research	<i>Use related WEF nexus research to:</i> 1. Evaluate status, trends, dynamics, and implementation process. 2. Focus on assessing progress and merit in (nexus) implementation, comparison indexing and judging the quality of approach and indicators analysis. 3. Informing decisions makers and stakeholders.	9	(Zaman et al., 2017) (Basheer et al., 2018) (Mabhaudhi et al., 2019) (Ding et al., 2019) (Muthee et al., 2021) (El Gafy et al., 2017c) (Nhamo et al., 2020) (El Gafy et al., 2017b).
Action research	<i>Use related WEF nexus research to:</i> 1. Solve local resource problems that practitioner faces. 2. Bring action outcomes to the situation and people’s needs. 3. Involve practitioners and community in research design and benefits. 4. Focus in the present time of local setting and needs	7	(Lee et al., 2020) (Amina et al., 2020) (Seidou et al., 2020) (Laubscher and Cowan, 2020) (Seeliger et al., 2018) (Jobbins et al., 2015) (Pardoe et al., 2018)

bring to the community. The nine articles were focused on developing effective methods or country performance on the SDGs WEF nexus and informing policymakers and other relevant stakeholders about the current situation of resource management and positive scenarios that should be pursued (Mabhaudhi et al., 2019). The minimal review of seven articles identified new knowledge in action research. However, it is critical and necessary to address the ambiguities of many practitioners. The action study should be intended to provide an exciting opportunity to advance community interests and practical capacity building in the real-world challenges of demand and supply of WEF resources by fostering collaboration between resource sectors' management practitioners and researchers. Action knowledge helps the community decouple from related water and environmental pollution and minimize conflicts between the community and industry owners. For example, a study by Lee et al. (2020) has provided the local community surrounding the Khouribga mine in Morocco with tools and options to benefit from industrial phosphate residues in agricultural fertilizers. In addition, the study follows the WEF's nexus approach in applying the direct fertilizer osmosis (DFO) technique in the production of different fertilizers and has become a good example of action research which leads to practical solutions for the benefit of improved livelihoods and food security in Egypt (Amina et al., 2020).

3.3. A comprehensive review of government-funded projects

Overall, the results indicate that food projects accounted for the largest number of projects, appearing in 122 projects, followed by water projects at 95 and energy resources at 89. The results show an uneven distribution of water, energy, and food-related projects proposals and implementation preferences within or across resource sector management, which are particularly dominated by the institutions of the ministries of water, energy, or agriculture (Fig. 5). Concerning the projects implemented at the sectoral resource level without collaboration with other sectors, Fig. 5a shows that energy dominates with 58 projects, food follows with 54, and water with 29. At the same time, collaboration among sectors shows that only 26 projects cover the WEF nexus concepts; 54 projects show interest in the water and food nexus; 16 projects in the energy and food nexus; and five projects cover the benefits of both the energy and water nexus (Fig. 5b).

In mapping projects' distribution along with African countries, Fig. 6a shows that many water projects are established in some countries, such as Mali, Burkina Faso, and Niger in the West, Sudan in the North, and Uganda in the East, where more than six major water projects were reviewed, while other countries typically have between four and six projects. Many countries have a small number of large energy projects (Fig. 6b), while food security projects are mainly concentrated in the East Africa region (Fig. 6c).

The results also show that most projects in the water-related projects are water-food nexus projects (Fig. 6a). This is particularly in agriculture, where water harvesting techniques, controlled grazing projects, and awareness are shown to have increased benefits for food production, reducing erosion and increasing carbon stock in Senegal, Uganda, and other countries in Eastern Africa region. In Tunisia, 60 micro-projects under major projects have been identified in official reports to improve irrigation infrastructure and protect land from wild Boars. Other projects, such as in Uganda, are proposed to treat wastewater for agricultural and energy purposes. In Central Africa, for example, a programme to reduce the vulnerability of rural and urban areas to climate change, together with promoting water resource management awareness, has been proposed. Agriculture, livestock, and water management extension services have shown effectiveness in Ethiopian and Eritrean governmental water and energy resources institutions. Water and food ministries are also proposed to strengthen monitoring and early warning systems and build institutional capacity for water resource management in Lesotho and Kenya.

On the other hand, 89 energy related projects were examined; among them, 58 exhibited a high preference for the energy sector with their own direct interests apart from collaboration with other sectors (Fig. 6b). This includes prioritizing energy security, sustainability, and efficiency by increasing the adoption of energy-efficient building designs, practices, and materials, enabling a policy, institutional, and legislative framework for energy efficiency, and enabling energy appliances efficiency improvements. It also looks at increasing electricity output in small local enterprises. For instance, solar energy projects take a big share to supply small local enterprises in Egypt. The Egyptian photovoltaics (PV) project has operated 109 solar system plants in 13 governorates with a capacity of 8.2 MWp to save electricity for 16 industrial projects and six commercial projects.

In Equatorial Guinea, minor hydropower (4.2 MW on Bioko Island) and other renewable energy were established as energy solutions for the small islands. Mali is promoting the production and use of *Jatropha* oil as a sustainable biofuel. Increases in modern energy-efficient projects are committed to in several nations to mitigate the Paris Agreement and climate change adaptation. These include promoting investments in small-to medium-scale renewable energy technology in the electricity sector via policy planning. Projects in Benin, Cabo Verde, Rwanda, Gambia, Liberia, Sierra Leone, Tunisia, South Africa, and Uganda have created energy efficiency-enabling policies, institutional and legal frameworks. Empowering regulatory mechanisms, such as the periodic updating of minimum energy performance standards (MEPS) for lighting products and associated labeling requirements, provide policy support for deploying high-efficiency lighting technologies, such as assistance to local manufacturers in transitioning to LED lamp production and improving product quality. It is also a worthwhile initiative to

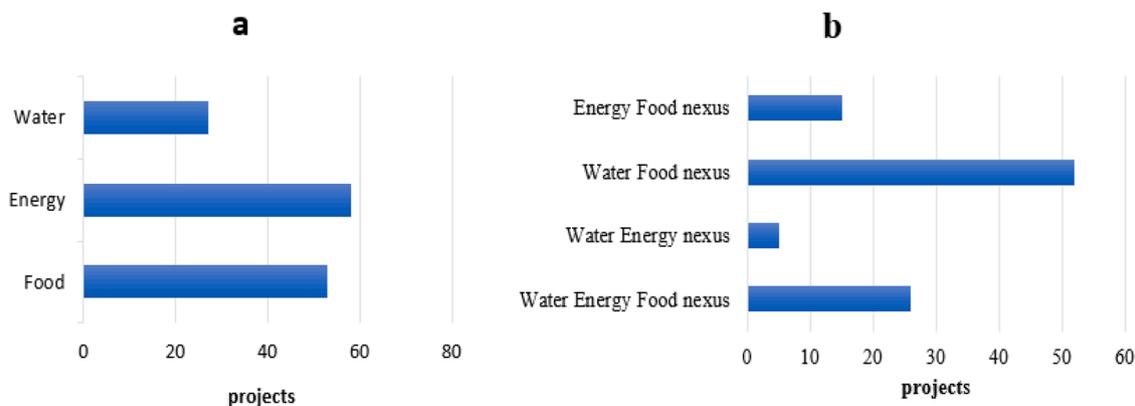


Fig. 5. Project allocation within resource sectors: (a) illustrating the number of projects implemented in a single sector, (b) showing projects implemented among sectors.

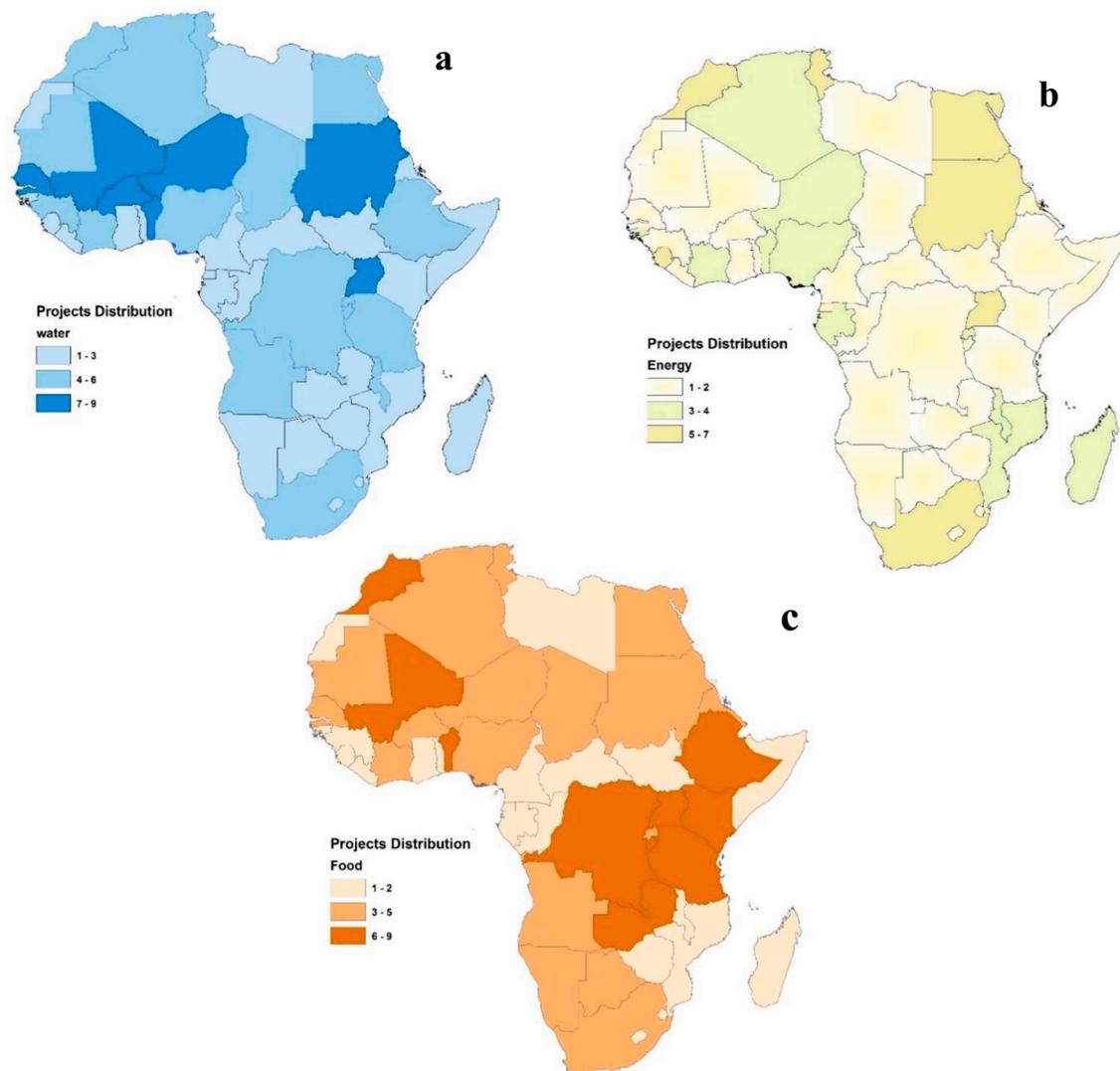


Fig. 6. Distribution of water, energy, and food resource projects across African countries: water projects (a), energy projects (b), and food-related projects (c).

establish incentives and market mechanisms that ensure supply and encourage demand for energy-efficient stoves and firewood/charcoal projects involving integrating technology into energy processes.

Similarly, 122 projects have been identified to improve food security through agriculture and land management, address climate change, conserve agro-biodiversity, and restore ecosystems and landscapes (Fig. 6c). For example, 51 projects demonstrated an intention to increase farmer resilience to climate change, market knowledge and capacity, and agricultural output through the empowerment of agro-industrial and food industry owners. Other projects are accomplished by providing incentives to local people's food value chains and the empowerment of agroforests. Many countries, especially in East Africa, such as Tanzania, Uganda, Zambia, Kenya, Ethiopia, Burundi, and the Democratic Republic of Congo (DRC), have established agro-industry projects to manage waste and fertilizer manufacturing, recycle wastewater, and convert biomass waste to energy. Among the coastal region's projects, preserving fishing incentives, enhancing the value of fishing production and processes, and reimagining fishing policy (e.g., in Cabo Verde, Mauritania, and Zambia) are much dominated. Numerous projects that significantly promote agro-sylvo-pastoral systems in Western Africa have been initiated and have impacted animal production output. Other projects in the areas of hydrometeorological and agricultural meteorological monitoring and forecasting, as well as investment and technology, have had a significant impact on the implementation of food

security in many African countries.

3.4. Research and projects statistical analysis

3.4.1. Similarity analysis

The cosine similarities have been calculated to understand similarities and differences between the messages given by writers in the corpus of research documents and project reports. This involved three different corpus documents with words coded on the same excel sheet for further analysis. It is analyzed based on similarities between the titles of their documents, objectives, activities, and targets in three different resources. The message documents of WEF nexus research show a similarity index of 0.44 towards the WEF nexus projects implemented. The messages written in the documents of WEF nexus projects and the WEF resource projects have a 0.3 similarity index, while the lowest value of the similarity score accounts for research texts and applied projects report text with 0.25. Overall, all documents analyzed show a poor similarity between themselves, which is typically less than 0.5, the minimum value considered for significant similarity between values. This should indicate some gaps in the understanding of WEF nexus concepts in terms of sector-based level between scholars and practitioners.

3.4.2. TF-IDF analysis

The TF-IDF (term frequency-inverse document frequency) analysis is used to assess how common or rare core words expressing seven-core opportunities of applying nexus approach exist in both documents of scholars and projects implementers. The results indicate that in research articles (Fig. 7a), words related to capacity building and production are significant and frequently appear in a large number of documents due to their high TF-IDF score, whereas words related to ecosystem and governance appear to be rare in the messages of scholars' findings. Impressively, the results of the TF-IDF analysis in the WEF nexus project reports (Fig. 7b) indicate that words related to production and ecosystem are much more prevalent, owing to their high TF-IDF score, whereas some opportunities expressed in the words "incentive" and "policy" appear to be extremely rare in the corpus of nexus project reports. The same as in Fig. 7c, corpus words representing production and governance were relevant with a high TF-IDF score, but other words such as capacity building and ecosystem appeared to be uncommon and rarely used in the projects' objectives activities, or intended outcomes.

3.5. Nexus profile alignments with the Bonn nexus mandate

This session illustrated the results of the alignment of the WEF's nexus implementation profile with the nexus mandate of the Bonn conference and the SDGs. In general, by developing and establishing policy and management ideas for these resources, the Bonn Nexus conference in 2011 has shaped the discourse on what has become commonly known as the interactions of water, energy, and food resources. Among the outcomes of the conference was the establishment of three guiding concepts for implementing the WEF Nexus: investing in sustainable ecosystem services, doing more with less, and accelerating access and participation of the poorest people. Increased resource productivity, waste resource management, economic incentives,

governance and policy coherence, ecosystem services, poverty reduction, and social awareness are among the seven essential opportunities to pursue in nexus implementation stated in those principles (Hoff, 2011). These targets have followed the sequence of the UN agenda as illustrated in Table 4, which highlights the number of scientific papers and projects proposed on each opportunity.

Following the analysis of the Bonn principles, 8 articles and 83 proposed projects are recorded to raise awareness of the increasing resource productivity. Some research articles focus on water productivity techniques emerging in a concert of water conservation, crop water footprint, and energy production policies (Debbbarh, 2019; Gulati et al., 2013). Others emphasize using the WEF nexus to determine agricultural profitability through budget model analysis (Bazzana et al., 2021; Leanne et al., 2018). Indeed, projects related to productivity are aligned to help local communities and institutions increase productivity and resource security and mitigate climate change. Most of these projects are assisting farmers in treating livestock manure to produce biogas and liquid fertilizer, which has related benefits in terms of food and energy resources (Jobbins et al., 2015). Other projects are helping the community mitigate climate change by improving access to modern cook stoves, mini and micro-hydropower plants, solar energy, bi-digester technology, capacity-building, investment in clean energy technology, and upgrading community's adaptation to climate change adaptation (CCA) technologies and practices.

Another nexus opportunity was presented in waste resource management, with limited research interest. Only two papers discuss some details of promoting waste recycling and reuse in the water, energy, and food resource sectors, along with sustainable development. This includes study by Gulati et al. (2013), which stresses the importance of connecting the whole chain of food resource production from farm to table, to minimize waste and production loss. AbdelHady et al. (2017) use their study to indicate how system modeling could be critical to

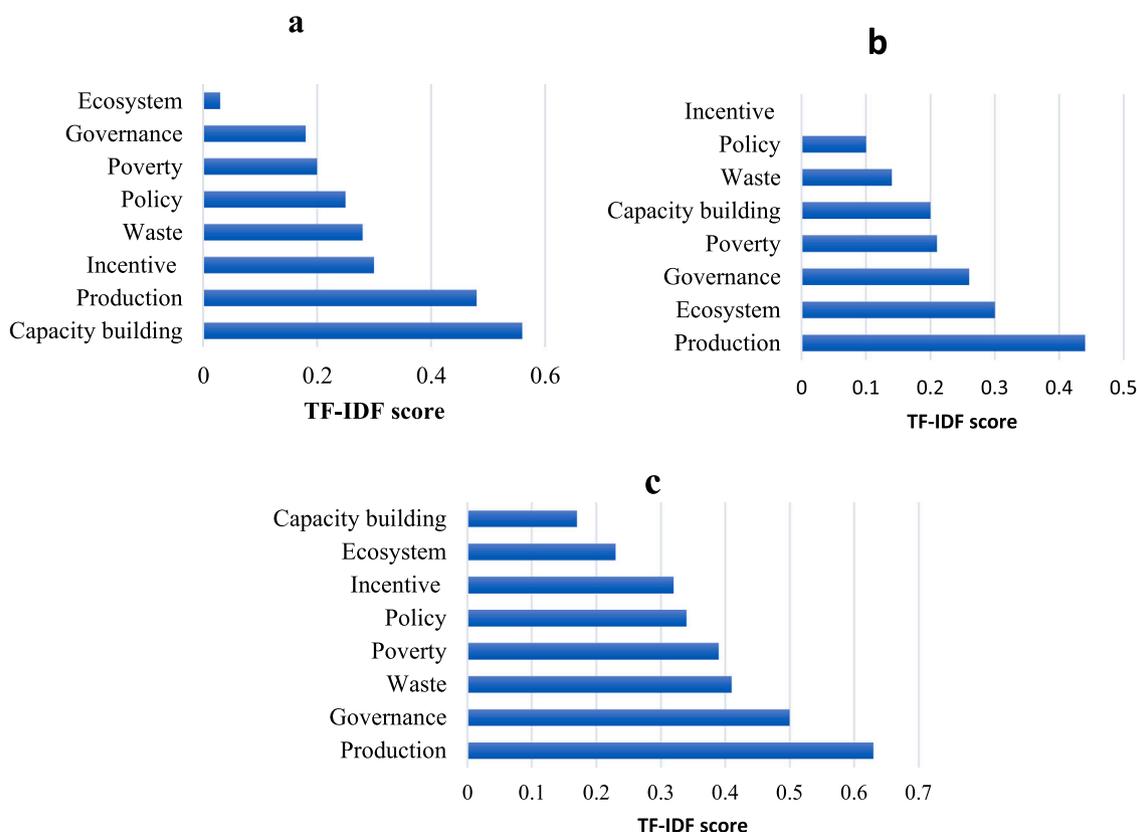


Fig. 7. Frequency of TF-IDF in nexus conceptions opportunities, (a) TF-IDF in research documents, (b) TF-IDF in nexus projects, and (c) TF-IDF in WEF applied projects.

Table 3
Similarity of Research and projects documents on WEF nexus perspective.

Similarity	Research	Nexus projects	Applied projects
Research	1	0.44	0.25
Nexus projects	0.44	1	0.30
Applied projects	0.25	0.30	1

Table 4
WEF nexus research and projects profile into Bonn nexus principles and SDGs.

Opportunities	The intervention of scholars/Polycymakers	SDGs associated	N° Projects related	papers reflected
Increase Productivity	Water Use harvesting, innovation in water management	6.4, 6.5, 12.3	83	Leanne Bazzana et al., (2018, 2021) (Debbarh, 2019)
	Biofuel generation from land restoration, promoting renewable energy use in water supply	7.2, 7.a		
	Genetic engineering for crop resistance	2.4		
Waste resource Management	Efficiency consideration of energy and water resource in modern food production		16	,AbdelHady et al. (2017)
	Wastewater resource use, Re-use of waste, Land rehabilitation with biofuel crops promotion	6.3, 11.6 12.3, 12.5, 7		
Governance, Institutions and policy coherence	Re-use waste, wastewater energy integration		26	Simpson and Jewitt Mabhaudhi Pardoe Nhamo Stein Ololade et al., (2019, 2019, 2018, 2020, 2018, 2017)
	Social Innovations, Political wills	10.2, 13.3, 9.b,		
	Institution’s responsibility	17.13–15		
Benefit from productivity ecosystem, Incentive	Decentralization, co-development		15	Githiru et al. (2017) (Imasiku and Ntagwirumugara, 2020)Yang Muthee et al., (2018, 2021)
	Reshape policy	14.1, 15.1		
Poverty	Restoration of ecosystem, Green & Conservation agricultural, Fight against climate change risk	2.4, 11.b, 13, 2, 11	10	Jobbins Mabhaudhi et al., (2015, 2019))
	Agri-ecosystem, Local goals consideration (water, Energy, food livelihoods)	2.3, 1.a, 1.b, 5.4		
Capacity building	Promoting modern & Green agriculture	15.9, 17.15	62	Hoffmann Ogbolumani and Nwulu Okola Yang Basheer Nhamo El Gafy Lee Amina Seeliger Jobbins et al., (2017, 2021, 2019, 2018, 2018, 2020, 2017b, 2020, 2020, 2018, 2015)
	Non-farming employment, Local goals consideration (water, Energy, food livelihoods)			
	Social learning, System thinking, developing Analytical tools, Scenario for future resource awareness,	13.3, 14. A, 15. c, 17.8		
	Trade-off analysis and promoting synergies, technology	17.18		
	Monitoring informs policy & regulation,			

categorizing resource wastage management in farming production, drainage water re-use, and energy efficiency production. In addition, 16 projects are registered in the conversion of waste into reusable resources such as biochar and fertilizers in many countries such as Tanzania, Benin, Niger, Lesotho, Uganda and Ivory Coast.

Four papers have been written on opportunities to integrate sustainable ecosystem management into the WEF nexus prospects to better leverage its productivity and three papers also recorded promoting incentives for ecosystem conservation. AbdelHady et al. (2017) indicated that adopting a nexus approach to value ecosystems can harmonize water, energy, and food resource use in specific areas. Githiru et al. (2017) made an interesting discussion on managing landscape ecology functions for either water, energy, or food needs, involving nexus perceptive. Imasiku and Ntagwirumugara (2020) also argue that linking the ecological balance of human activities to the WEF nexus promotes ecosystem sustainability. The same applies to projects implemented in ecosystem services through incentives for the community around conservative areas. The most significant projects are found near the coast, where they provide chances to conserve aquatic biodiversity and encourage fishing activities for the community. Other agroforestry

projects in Benin and the DRC have demonstrated positive productivity for supporting soils to be more productive, preventing soil erosion climate change, and contributing to energy provision through biomass.

Other findings show limited literature on the opportunities that the WEF nexus approach should offer in policy guidance and coherence. The only six articles on record, included a study by Elagib et al. (2021) on the need to improve the management of national institutions and reshape transboundary riparian resource policy. In terms of policy-related projects, 26 projects are being implemented under the WEF’s policy empowerment within institutional capacity building, national resource strategies, climate risk management, clean technologies, and standardization of resource exports and imports. Scientific research and projects related to poverty reduction still require considerable effort (Jobbins et al., 2015; Mguni et al., 2020; Pardoe et al., 2018). The capacity-building potential was addressed by 62 applied projects and ten research papers. Two findings indicate that most of the research results in the capacity building nexus publications are devoted to developing analytical and evaluation tools to assist policymakers (Imasiku and Ntagwirumugara, 2020; Nhamo et al., 2018).

4. Discussion

4.1. African WEF resources context and challenges in nexus approach

The implication of WEF nexus framework in Africa shows good ways to keep serving the future generation, but their current implementation is still hard to achieve (Muhirwa et al., 2022). This study reveals that there are many reasons for this including a lack of practical understanding of each sector's context in terms of physical resource availability, accessibility sectoral objectives, lack of common understanding, and lack of political consideration for each sector before proposing an integration approach. The International Institute for Environment and Development (IIED) also shows that food insecurity prevailing in most African countries leads to trade-offs and conflicts of interest with other sectors, which undermines the integration of WEF nexus in Africa (Gusenbauer and Franks, 2019; Hou-Jones et al., 2019). In examining the status of the WEF sectors, the results show that water was the most frequently used word in the corpus (342 times) in both research and applied projects. Water resource is also considered the main pillar of the WEF nexus projects (Udugama et al., 2020).

Despite Africa being endowed with abundant water resources, the continent is ranked at the front line of water scarcity (Mugagga and Nabaasa, 2016). All African countries face water scarcity, whether physical water scarcity in most northern and southern African regions or economic water scarcity in other African countries (Naik, 2017). A study shows that the challenges of meeting human water needs are generally lumped together with the challenges of water management, which may jeopardize the water sector's mutual contribution to other food and energy sectors (Kuma et al., 2020). High population, changing population lifestyles, urbanization, climate change, and poor agricultural practices are also considered in the water resource constraints to effectively contribute to the WEF nexus (GRI, 2018; Nhamo et al., 2018).

The energy scarcity and demand are also interchangeable challenges in Africa (RES4Africa, 2019c). The adaptation of the WEF nexus approach in energy sector has required a lot of attention. For example, more than 75 % of sub-Saharan Africa's population lacks access to electricity, which is regarded as a high priority, regardless of the costs or trade-offs that will be required in other sectors (Blankenship and Golubski, 2021). This concern was also observed in the results of this study, as most of the projects implemented in the energy sector are energy sectoral benefits rather than collaboration with other sectors. Some regions of Africa are more vulnerable, especially sub-Saharan Africa, which is experiencing a lack of access to electricity, little connection between energy production with other such as water and food sectors.

The inclusion of the food sector in the WEF nexus has many challenges also, due the high priority given to the fight against food insecurity and hunger facing most African countries (Simpson et al., 2019). For example, a study assessing the 36 most food-insecure countries in the world shows that 28 countries are in Africa, representing half of the continent's countries (FSIN' 2019). Nevertheless, the predominance of traditional agricultural practices, resulting from low food production and security investment, provides more than 75 % of the population's direct food supply and uses more than 80 % of total water withdrawals; needs a critical consideration (Muhirwa et al., 2021). Some challenges of land degradation, climate change, poor management, limited agriculture practices, and the lack of inclusion of local communities in projects implemented in their surroundings are also challenging food security sector and the WEF security nexus in general (Hirwa et al., 2021). Gulati et al. (2013), study assessed the interconnectedness of WEF resource systems in South Africa and suggested that food security necessitates integrative thinking in strategic planning with other resources.

4.2. Research and Projects scope and attribute on WEF nexus

The WEF's nexus security approach has a broad scope,

interconnecting water, energy, and land resources to ensure water, energy, and food security, promote the economy, and reduce climate change (Endo et al., 2017; Hoff, 2011). In literature, research carries positive or negative connotations depending on the actors involved and their attitudes towards a particular development project. Despite the interesting note that at present there is no explicit definition of WEF nexus at the global level and some consider WEF nexus a "fuzzy approach" in practice (Cairns and Krzywoszynska, 2016; Olawuyi, 2020), this study has shown that understanding the principles of nexus initiation, governmental priorities, and the availability of geophysical resource distribution can serve as a good scope to follow in WEF nexus implementations. For example, many WEF nexus studies in Africa focus on capacity building, productivity improvement, governance and policy recommendations. Food resources, from a practitioner perspective, have a broader scope than other resources.

Following the type of knowledge provision by researchers in the WEF nexus in Africa, many studies are attributed to basic or theoretical knowledge generation, which is consistent with previous research (Botai et al., 2021). However, countries get closer to the target SDG agenda in 2030, empirical research on the WEF Nexus' ability to support SDG implementation becomes less certain but highly needed for policymakers and practitioners with demonstration of action knowledge. Projects implementation scopes are mostly based on water, energy, food, agriculture, climate change, and landscape conservation projects, which cover almost all of the projects evaluated. The scope of selecting projects is sometimes influenced by the project funding; for example, the GEF scope is more focused on climate change, landscape management, biodiversity conservation, and Persistent Organic Pollutants. Part of the nexus literature justifies a lack of understanding of WEF nexus governance and a reduced willingness of policy makers, especially in relation to integrated policies across sectoral directions and the costs of trade-offs between sectoral benefits (Weitz et al., 2014). This can limit nexus approach for actualizing its ambitions effectively.

Indeed, the main priority for practitioners is to attribute and transform the context of nexus research into actionable knowledge that meets the demand for sustainable resources and increases production. According to the results, 35 % of the proposed projects by policymakers aim to increase resource production while an estimated 37 % of research projects are attributed to capacity building for policymakers. The capacity building provided by research is criticized for being more theoretical and neglecting the demand for livelihood resources (Mugagga and Nabaasa, 2016). The contradiction between researchers' priorities and policymakers has also been justified by poor correlation results (see Table 3) which means different consideration of understanding and the importance of the WEF nexus in the schedule of policymakers versus WEF nexus researchers. In response, some research mentioned the need to develop technology and engineering to support the practice of WEF nexus in increasing the community's resource production needs in a sustainable manner (Belmonte et al., 2017). This research recommends close collaboration between researchers and policymakers in addressing the WEF's universal access programs to better find alternative solutions to minimize the high trade-offs in resources use and loss. Contributions from social scientists are pointed to understand the potential and constraints of social variables such as population, gender, and conflict influence (Bromwich, 2015; Villamor et al., 2020).

4.3. WEF nexus projects implementation priorities and context in Africa

The implementation of nexus perspectives in Africa is still mainly envisaged through joint projects between the water, food, and energy sectors, often with the support of foreign partners (Pardoe et al., 2018). This study for instance shows that African governments or institutions contributed to only 8 % of the projects evaluated, while the remaining 92 % of projects are co-financed by foreign partners. The results are similar to the recent study which observed that Africa is the last continent with the lowest number of WEF nexus-related projects, with a share

of 7.4 % of the global nexus research, projects, and related work between 2017 and 2020 (Sarkodie and Owusu, 2020). The African self-funding projects are dominated by the North and South African regions. Co-partner funding are several institutions including the World Bank, the Global Environment Facility (GEF), British and American agencies such as USAID and GIZ, as well as others that have signed collaborative partnerships with African governments are recorded. The GEF presented a basket of funding for African government projects, with funding for over 77 % of the projects analyzed specifically for climate change adaptation, landscape restoration, biodiversity conservation, and persistent organic pollutants.

The distribution of projects was found to be related to the context of each region. For example, the North African region and South Africa are more interested in energy-related projects. Both regions, especially the North, require significant energy for groundwater pumping, desalination, and wastewater management (Maftouh et al., 2022). The proposed projects in Sub-Saharan Africa, particularly in East Africa, are more focused on food security issues. The East African region is the most food-insecure globally (Gusenbauer and Franks, 2019). The West African region is slightly stable in terms of the availability of WEF resources as it accounts for more than 60 % of the total value of agricultural production on the continent (Gusenbauer and Franks, 2019). Most West African countries are engaged in all sectors of resource projects, except for Sahelian countries such as Mali, Niger, Burkina Faso, and Senegal, which also face the problem of water resources.

Throughout the implementation process, institutions in the Ministries of Natural Resources, Environment, Water, Energy and Food, Agriculture and Energy have the most significant number of projects implemented in each sector or in two sectors (see Fig. 5). Other governmental Institutions such as infrastructure, finance, urbanization and technology institutions are also widely involved in WEF nexus projects. In the study interviews with some policymakers in government agencies manage WEF resources mentioned that the existence of a specific agenda and targets for each WEF resource department or government agency are factors that make them work in silos (Mohtar, 2016). Besides that, private sectors seem to be very limited in the practical implementation of the nexus (Endo et al., 2017). The results show that a high number of WEF nexus projects (70 %) are implemented by WEF-affiliated research institutions, while government institutions implement only 30 %. This is in line with the findings of Endo et al. (2017) that 77 % of the projects established in WEF nexus projects globally were for research and science policy objectives.

4.4. Policy implications and future directions

The WEF's security nexus in Africa aligns with many continental, and regional integration policies targets. For instance, Abuja's treaty of trade liberalization, signed in 2013, promoted complementary strategies such as the Agriculture Development Programme. Other agreements on Africa's trade raised the issue of the energy sector's input into the productive flow of challenges that Africa faced (UNCTAD, 2019). The African Union Summit 2014 (Malabo Declaration) on agriculture goals AUC (2014) showed hope to eradicate food insecurity and poverty by improving agricultural practices, including modern irrigation, energy in agricultural inputs financing. The African Union agenda in 2063 includes various strategies and policies to increase energy resources, eradicate hunger, and access clean water. Other policy targets are decreasing food imports and raising intra-African trade in agricultural food production to 50 % by 2045 (AUC, 2015). The Africa Water Vision for 2025 for equitable and sustainable water use for socio-economic development (AfDB, 2019). Land policies have also been established to increase the sustainable production of biomass resources and reduce GHG emissions in the Eastern Africa region by about 10 % (Van de Ven et al., 2020).

However, African countries still prefer silos governance in WEF resources management. Studies recommend that policymakers move

beyond an apolitical and positivist conceptualization of the WEF nexus and develop innovative technology for the nexus cycle (Terry, 2020). Focus group interviews with policymakers for WEF security nexus in Tanzania showed the constraint of nexus emerged between them when they met at a common project level, often with the support of international development partners or a wide range of organizations (Pardoe et al., 2018). The above arguments of policymakers support the rationale of research about the lack of nexus ownership and governance hindering the ability of nexus to cope with SDGs in Africa (Ding et al., 2019). Also, other challenges in policymaking evidenced from a study conducted in the Akagera Basin Rwanda mentioned that the policy set for increasing energy and agriculture has shown some inconsistency and conflict with each other (Oliver et al., 2018). This was also found in regional policies of agriculture expenditure and food security in Malawi, Zambia, Zimbabwe, and Mozambique to energy and water scarcity (Nhamo et al., 2018). Therefore, understanding different policies' coherence is crucial for achieving SDGs related to the WEF resource security. Some studies have underlined the effectiveness of considering all levels of decision-making, from an operational level and tactical decision level to strategic decision-making (Sarah Namany and Govindan, 2018).

5. Conclusion

The implementation of the WEF security nexus was discussed among policymakers, researchers, and African partners to understand their current impacts, roles, and constraints. The research and allocation of applied projects have many inconsistencies and trade-offs in their scope, indicated by their minimum similarity index. Since much of the WEF nexus research is aimed at capacity-building objectives and policy recommendations, adjustments are needed to link theory to practice, thus providing opportunities for increased resource production sustainably. Siloed governance still dominates policymakers based on the focus of their projects, activities, and expert findings. Integrating the WEF nexus philosophy into African practice requires establishing additional policy and research platforms that discuss the potential adaptability and integrated governance of the WEF nexus at different partnership levels. Revisiting the concepts of the WEF nexus approach and the advantages of its design mentioned at the Bonn nexus conference can bring more benefits to make this approach beneficial and applicable. Further studies should identify the most effective ways to integrate the WEF nexus philosophy into the "challenges and realities of sectoral silo systems." Understanding the socio-economic and environmental limitations of this nexus approach in the African context needs to be further discussed.

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

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