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# Exploring systems analysis and interdisciplinary research approaches for sustainable development in Africa

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**Abstract**
Research on sustainable development in Africa is essential for addressing environmental, social, and economic challenges. This study examines the landscape of the United Nations sustainable development goal (SDG) research, focusing on systems analysis, interdisciplinary research trends, and the influence of funding on research priorities. A systems analysis approach was used to review articles incorporating system modeling, network analysis, system dynamics, complex adaptive systems, socio-ecological systems, life cycle assessment, and system theory. Using a corpus of publications retrieved from Dimensions database, Machine learning-based BERTopic modeling identified six thematic clusters: integrated health systems, governance and policy, environmental sustainability and impact assessments, climate resilience and food security, biodiversity and conservation, and educational systems. Four key topics—healthcare, governance, environmental sustainability, and climate resilience—were analyzed through keyword co-occurrence and SDG mapping to assess alignment with global sustainability priorities. The findings reveal strong interdisciplinary connections, with research aligning significantly with SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Stakeholder engagement is critical in governance, healthcare, and environmental policies, yet institutional constraints and funding limitations restrict inclusive collaboration. Education, gender equality, and innovation-related research remain underexplored, emphasizing the need for broader academic focus. Funding trends prioritize climate and energy research, leaving gaps in social and institutional sustainability. Future studies should explore governance models, transboundary resource management, and education systems to address existing knowledge gaps. Strengthening digital tools, interdisciplinary frameworks, and policy-oriented research can increase sustainability efforts in Africa, whereas diversifying funding sources can support underrepresented SDGs for a more balanced approach to sustainable development research.

**Keywords** Systems analysis, Sustainable development goal, Topic modeling, Renewable energy, Climate action, Public health, Africa, Water sustainability, Coastal governance

## 1 Introduction

Africa stands at a crossroads in its development trajectory, characterized by a complex interplay of opportunities and challenges. While the continent possesses abundant natural resources, cultural diversity, and human capital, it also faces persistent issues such as poverty, inequality, environmental degradation, and inadequate infrastructure [1–5]. Addressing these challenges and unlocking Africa's potential for sustainable development requires a deeper understanding of the socioeconomic, environmental, and governance dynamics at play, along with innovative, evidence-based solutions. Therefore, amid Africa's complex and interconnected challenges, systems analysis has emerged as a crucial tool for understanding the dynamics of sustainable development. Systems analysis provides a holistic framework for examining the interactions between various components of socio-ecological systems, identifying feedback loops, and assessing the potential impacts of interventions [6]. By adopting a system thinking approach, researchers and policymakers can gain insights into the underlying drivers of sustainability challenges, anticipate unintended consequences, and design interventions that address root causes rather than symptoms. In recent years, the pursuit of the United Nations Sustainable Development Goals (SDGs) has become increasingly critical, particularly for Africa, a continent facing multifaceted challenges such as poverty, inequality, weak health and education systems, environmental degradation, climate vulnerability, and funding constraints alongside significant opportunities [7–10]. The SDGs provide a comprehensive framework for addressing key dimensions of sustainable development, including poverty eradication, environmental sustainability, social equity, and economic resilience [11]. However, progress towards these goals has been uneven across African countries, with disparities between urban and rural areas and varying national capacities to implement sustainability policies effectively [12]. Achieving the SDGs requires interdisciplinary approaches, robust research frameworks, and coordinated efforts among policymakers, researchers, civil society organizations, and funding agencies [13]. Africa faces significant financial gaps in SDG implementation, necessitating innovative financing mechanisms to support clean energy transitions, climate adaptation, and sustainable infrastructure development [14–16]. Emerging models of community-led conservation have demonstrated success in preserving biodiversity, often surpassing state-managed initiatives, reinforcing the importance of localized approaches to environmental sustainability. These developments highlight the need for regionally tailored strategies, stronger multistakeholder engagement, and enhanced research capacity to bridge knowledge gaps and accelerate Africa's sustainable development trajectory.

Systems analysis offers several benefits for advancing the SDGs in Africa. It enables stakeholders to adopt a long-term perspective, considering the intergenerational implications of policy decisions. By recognizing the complex interconnections between social, economic, and environmental factors, systems analysis promotes resilient and adaptive development pathways that prioritize long-term well-being [17]. Additionally, it facilitates the integration of diverse knowledge systems, including indigenous knowledge, scientific evidence, and stakeholder experiences. When traditional practices and local wisdom coexist with modern technologies and global trends, participatory and inclusive decision-making becomes essential for ensuring relevance and sustainability [18].

Another aspect of systems analysis crucial for addressing Africa's challenges is stakeholder engagement. Bringing together governments, civil society organizations, academics, private sector actors, and local communities enables the codesign and implementation of contextually relevant and socially equitable solutions [19]. First, stakeholder engagement builds trust, fosters mutual understanding, and enhances the legitimacy of decision-making. Involving stakeholders in policy and project development ensures interventions align with local needs, preferences, and priorities [20]. It also promotes ownership and empowerment, enabling communities to drive development from the grassroots level. Second, stakeholder engagement supports the coproduction of knowledge and innovative solutions. By leveraging the collective expertise and creativity of diverse actors, systems analysis can identify leverage points for intervention and catalyze transformative change [21].

Despite considerable progress in sustainable development research within Africa [22–25], discernible gaps remain in understanding how interdisciplinary approaches, stakeholder engagement, and funding dynamics collectively influence the achievement of the SDGs. The intricate interplay between these factors and their impact on sustainable development practices necessitates a detailed examination. Therefore, guided by the preliminary findings, this study has the following research questions:

- RQ1: How does systems analysis shape sustainable development efforts in Africa, and what systemic barriers affect collaboration?
- RQ2: How does interdisciplinary research on sustainable development in Africa align with SDG priorities, and where do gaps remain?
- RQ3: How do funding patterns influence sustainable development research in Africa, particularly in underrepresented SDG areas?

This study makes several important contributions by integrating established framework for the literature review with machine learning-based BERTopic modeling, enabling a structured yet data-driven approach to identifying interdisciplinary research themes in Africa's sustainable development landscape. The use of keyword co-occurrence and SDG mapping frameworks provides insights into research concentration and gaps, aligning findings with global and regional development priorities. A systems analysis approach is applied to examine stakeholder engagement, governance structures, and policy interactions, offering a deeper understanding of how different sectors contribute to achieving the SDGs. Additionally, the study critically examines funding dynamics, revealing how financial constraints shape research priorities in Africa and limiting the inclusion of underrepresented SDGs such as education, gender equality, and innovation.

The structure of this paper is as follows. Section 2 opens with a review of the literature, pinpointing the specific gaps our study aims to fill, particularly focusing on stakeholder engagement and the SDGs. In Sect. 3, we detail the methodologies employed for data collection and analysis. Section 4 presents our findings, which are structured around the effects of stakeholder engagement as analyzed through a systems analysis approach and interdisciplinary research using the SDG framework. Additionally, this section explores the impact of funding patterns on the scope of sustainable development research. Section 5 is dedicated to discussing these findings, including an examination of the challenges and limitations encountered in our research. The paper concludes in Sect. 6, where we mention key insights derived from our analysis.

## 2 Related work

The published literature on systems analysis in the context of sustainable development in Africa reveals several prominent and interconnected research themes. These themes reflect the continent's complex socioeconomic, environmental, and governance challenges, as well as the opportunities for innovation and progress toward the SDGs. This section synthesizes findings from the literature, organized into five key thematic areas: sustainable energy transitions, circular economy and resource efficiency, water and urban systems, capacity building and knowledge exchange, and integrated SDG-focused approaches (Table 1).

### 2.1 Sustainable energy transitions

One of the most well-developed themes in the literature is the application of systems analysis to sustainable energy solutions, reflecting the centrality of SDG 7 (Affordable and Clean Energy) to development in Africa. Studies such as Carvalho et al. [26], Seglah et al. [27], and Raman et al. [28] have assessed the environmental and socioeconomic potential of renewable energy sources, including bioenergy and biomass. These studies emphasize the role of clean and affordable energy in alleviating energy poverty, reducing greenhouse gas emissions, and supporting inclusive economic growth. Systems modeling approaches in these works illustrate how renewable energy can catalyze progress across multiple SDGs, including SDG 1 (No Poverty) and SDG 10 (Reduced Inequalities), by expanding access and fostering equitable development.

### 2.2 Circular economy and resource efficiency

The promotion of circular economy principles is another prominent research theme, closely linked to SDG 12 (Responsible Consumption and Production) and SDG 9 (Industry, Innovation, and Infrastructure). Studies by El Wali et al. [30] and Masindi et al. [31] demonstrate how circular management of material flows, such as phosphorus in agricultural supply chains and industrial waste streams, can improve resource efficiency, reduce environmental impacts, and support industrial sustainability. Systems thinking is used in these works to identify leverage points for closed-loop production systems, waste reduction, and innovative reuse strategies. Circular economy initiatives in Africa, as these

**Table 1** Key research themes, and focus in systems analysis for sustainable development in Africa

| Theme | Focus | Key studies |
|---|---|---|
| Sustainable energy transitions | Renewable energy potential, energy access, climate mitigation | Carvalho et al. [26], Seglah et al. [27] Raman et al. [28], Mukhtar [29] |
| Circular economy & Resource efficiency | Waste reduction, closed-loop systems, industrial sustainability | El Wali et al. [30], Masindi et al. [31] |
| Water & Urban systems | Water-energy-food nexus, integrated urban planning, resilience | David and Adepoju [32], Nyemba et al. [33], Simpson [34], Russo et al. [35]; Mavhungu et al. [36] |
| Capacity building & Knowledge exchange | Stakeholder engagement, interdisciplinary collaboration, institutional strengthening | Nyemba et al. [33], CHEPSAA [37] |
| Integrated SDG-focused approaches | Synergies & trade-offs among SDGs, holistic strategies | Mainali et al. [38], Gladkykh et al. [39], Mavhungu et al. [36], Masindi et al. [31] |
| Underexplored areas (noted as gaps) | Health systems, education systems | Leal Filho [24], Haldar et al. [40], Langnel et al. [41], Luken et al. [42] |

studies argue, also have important social and economic benefits, including job creation, innovation opportunities, and enhanced competitiveness of local industries.

### 2.3 Water and urban systems

Systems analysis has also been widely applied to water resource management and urban sustainability, aligned with SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities). Water-energy-food nexus studies, such as those by David & Adepoju [32], Nyemba et al. [33], and Simpson [34], address challenges of water scarcity, pollution, and equitable access by adopting integrated and interdisciplinary approaches. These works demonstrate how systems methodologies can identify synergies and trade-offs among competing water uses, foster sustainable governance, and guide technology-driven innovations. In urban contexts, research by Mavhungu et al. [36], Russo et al. [35], and Masindi et al. [31] explores how resilient infrastructure, waste management, and integrated planning can create inclusive, sustainable, and climate-resilient cities. Together, these studies underscore the need for holistic urban and water systems planning that accounts for social, environmental, and economic dimensions.

### 2.4 Capacity building and knowledge exchange

Building institutional capacity and fostering knowledge exchange are critical enablers of sustainable development and are prominent in systems analysis research. Works such as Nyemba et al. [33] and initiatives like CHEPSAA [37] highlight the value of interdisciplinary collaboration, stakeholder engagement, and participatory approaches in designing effective policies and interventions. These studies emphasize how systems thinking can bridge disciplinary boundaries, empower local communities, and improve decision-making by incorporating diverse perspectives and local knowledge. Such approaches contribute to the development of inclusive governance structures and enhance the ability of African institutions to lead SDG-aligned initiatives.

### 2.5 Integrated SDG-focused approaches

Finally, an emerging body of research explicitly applies systems analysis to understand and optimize synergies and trade-offs among the SDGs themselves. Mainali et al. [38] and Gladkykh et al. [39] demonstrate how integrated strategies can simultaneously advance multiple goals—such as linking energy sufficiency (SDG 7) with poverty reduction (SDG 1) and inequality reduction (SDG 10)—while mitigating unintended trade-offs. Other studies, such as those by Mavhungu et al. [36] and Masindi et al. [31], examine how municipal wastewater management and industrial sustainability contribute to both environmental and social development targets. These integrated perspectives reflect the inherently interconnected nature of the SDGs and demonstrate how systems analysis can inform coordinated policy and programmatic responses.

While existing research has made significant contributions to sustainable development in Africa, gaps remain in integrating systems analysis with underrepresented SDGs such as health, education, and institutional governance. Many studies focus on environmental sustainability and resource management, yet fewer address how systems thinking can enhance policy coherence, stakeholder engagement, and long-term capacity building. This paper addresses these gaps by examining the role of interdisciplinary frameworks in bridging governance, social equity, and sustainability efforts.

## 3 Methods

The research design as seen in Fig. 1 is explained below.

### 3.1 PRISMA protocol

In alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [43], this research meticulously follows a structured protocol for the identification, screening, eligibility assessment, and inclusion of publications. The robustness and reliability of the PRISMA protocol are well established, as it has been utilized in systematic literature reviews across various domains [44, 45]. The initial identification phase involved a comprehensive search of the Dimensions database provided by Digital Science. Singh et al. [46] highlighted the Dimensions database as a superior tool for bibliometrics of research publications, noting that its extensive journal coverage exceeds Web of Science by 82.2% and Scopus by 48.1%. The search strategy was constructed to capture a broad spectrum of systems analysis related terms, ensuring the inclusion of research that employs a systems perspective. The search query integrated key phrases such as "life cycle assessment," "systems thinking," "systems dynamics," and "complex adaptive system." The exact search query for the title and abstract was as follows:

> *((africa OR saharan) AND ("life cycle assessment" OR "life cycle thinking" OR LCA OR "System* Thinking" OR "system* dynamics" OR "network analysis" OR "complex systems" OR "system* engineering" OR "system* modeling" OR "system* analysis" OR "system* theory" OR "complex adaptive system" OR "simulation and optimization" OR "feedback loop")).*

The search was restricted to publications in the English language, covering the years from 2013–2023, coinciding with initial discussions about SDGs at the 2012 Rio + Summit. The screening process involved a careful review of titles and abstracts on the basis of the search terms. The initial search yielded a dataset of 1961 publications. The publications considered included articles, chapters, and proceedings. The document types

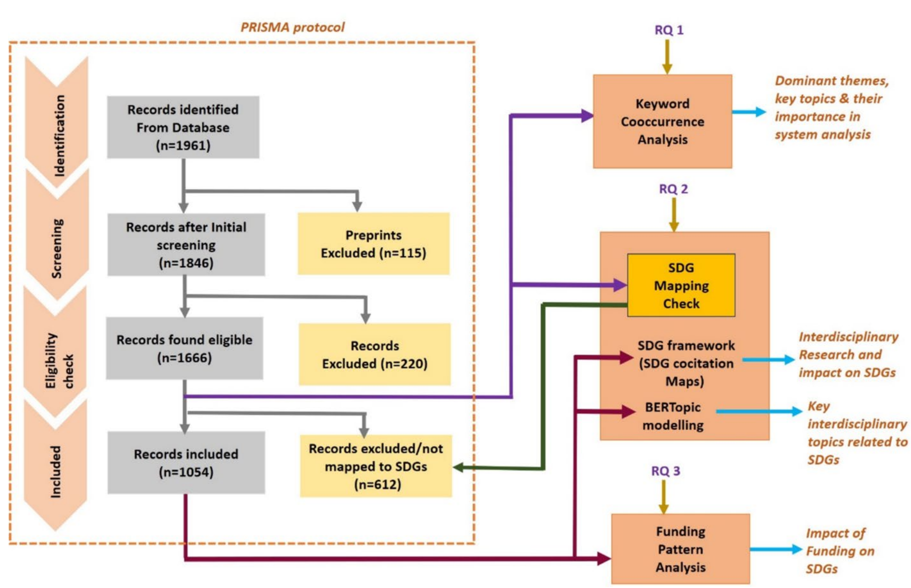


**Fig. 1** Research design

included research articles, research chapters, review articles, and conference papers. Preprints amounting to 115 were excluded during this stage. The eligible corpus, consisting of 1666 articles (Dataset1), underwent further scrutiny via the predefined SDG filter provided by the Dimensions database. Building on the application of precise SDG mapping techniques in research topics such as renewable energy [45] and cybersecurity [47] we adopted a similar approach to analyze research trends and their alignment with sustainability goals. The SDG mapping was applied to Dataset1, resulting in Dataset2 with 1054 papers that were directly mapped to the 17 SDGs.

## 4 Keyword co-occurrence

Dataset1 was utilized to conduct a systems analysis investigation (RQ1) via VOSviewer, a widely recognized tool for bibliometric network visualization and analysis [48]. This method involves generating a co-occurrence network of keywords, where nodes represent specific keywords extracted from the dataset, and edges (connections) signify their co-occurrence within the same publications. The size of each node reflects the frequency of keyword appearances, whereas the thickness of edges denotes the strength of their co-occurrence relationships. Clusters of keywords identified through VOSviewer's clustering algorithm represent thematic groupings or research subfields within the broader domain of systems analysis. These clusters provide insights into how closely related concepts coalesce around shared topics, revealing emerging trends, gaps, and potential areas for interdisciplinary integration [49]. This approach also allows for a quantitative understanding of the intellectual structure of the field. For the co-occurrence analysis, a minimum occurrence threshold of 5 was set to ensure meaningful and robust clusters. By visualizing keyword relationships, it becomes possible to identify dominant themes, peripheral topics, and the extent of their integration into systems analysis literature.

### 4.1 SDG framework

Dataset2 was subjected to interdisciplinary topic exploration (RQ2) via the SDG framework. Our approach acknowledges the interconnected nature of the SDGs, a complexity that network analysis literature, such as works by Le Blanc [50], has previously characterized. The use of cocitation maps illustrates the semantic proximity of SDGs, revealing conceptual relatedness as indicated by shared citations in the literature. The produced map visualizes each SDG as a node, with the node's size reflecting the extent of its presence in the research literature. The thickness of the lines connecting these nodes signifies the frequency of cocitations among the goals, thus illustrating the interconnectedness of the SDGs. This depiction reveals the SDGs as an intricate but unified framework that underpins efforts toward global sustainability. This study adhered to the SDG reporting guidelines established by the United Nations Statistics Division (UNSTATS) to ensure consistency and alignment with internationally recognized SDG classifications and indicators.

### 4.2 BERTopic modeling

Various topic modeling techniques exist, including nonnegative matrix factorization (NMF), probabilistic latent semantic analysis (PLSA), To2Vec, and latent Dirichlet allocation (LDA). Despite their widespread use, these methods often fail to capture semantic relationships between words and are not well suited for short-text formats [51]. In contrast, bidirectional encoder representations from transformers (BERT), developed by Google, introduces a deep learning-based approach to language modeling [52]. Unlike traditional models that rely on bag-of-words (BoW) and term frequency, BERTopic leverages embeddings that encode contextual meaning within a lower-dimensional space, leading to improved topic coherence and interpretability [53]. Compared with conventional methods, this embedding-based approach ensures a deeper understanding of text semantics [54, 55].

The topic modeling workflow in BERTopic starts by converting textual data into numerical representations through embedding vectorization. These embeddings are then refined via Unified Manifold Approximation and Projection (UMAP), which reduces dimensionality and groups similar data points for enhanced topic clarity [56]. To identify cohesive topic clusters, hierarchical density-based spatial clustering of applications with noise (HDBSCAN) is applied, allowing for the differentiation of dense areas while filtering out irrelevant data points. The class-based term frequency-inverse document frequency (c-TF-IDF) is subsequently utilized to extract the most significant terms within each topic cluster, ensuring that key concepts are properly highlighted [57]. For text representation, we implemented the "all-MiniLM-L6-v2" model, which is optimized for clustering and semantic search applications [58]. Document-topic assignments are determined on the basis of these extracted terms, with probability scores indicating the degree of association between a document and each identified topic [59].

To refine the modeling process, we adjust three primary hyperparameters: the n-gram range, the topic count, and the minimum topic size. A bigram range (1,2) was selected to capture both individual words and two-word phrases, balancing granularity with interpretability. We experiment with topic numbers ranging from 4–16 to optimize coherence while preserving specificity. A minimum topic size of 20 was set to maintain meaningful clusters, with the top 20 keywords for each topic ensuring focus without excessive detail. Stop words, including common terms such as "use," "add," and "related," were removed to minimize noise, aligning with previous recommendations [53]. Additionally, UMAP was configured with default parameters, document-topic probability calculations were enabled, and the language setting was fixed to English. The cosine metric was applied for measuring angular similarity between document vectors, ensuring robust topic differentiation. A random seed of 100 was used for reproducibility, whereas n_neighbors was set to 15 to maintain a balance between local structure and broader topic trends [60]. Topics were iteratively evaluated on the basis of coherence scores and intertopic distance, with a minimum separation threshold of 0.05 to ensure distinct topic boundaries. This process resulted in the final selection of 4 topics.

To validate the results, a manual evaluation was conducted by three domain experts, who reviewed topic coherence and relevance on the basis of extracted keywords and associated publications. This qualitative assessment ensured that the machine learning approach produced interpretable and meaningful outputs, following established BERTopic validation practices [61, 62]. Probability scores and citation metrics were also considered when the three most representative articles for each topic were selected, reinforcing the credibility of the unsupervised modeling approach. Although inter-rater reliability metrics were not formally computed, disagreements among the reviewers were resolved through discussion and consensus during a joint review session, ensuring alignment on topic interpretations.

## 5 Results

### 5.1 Systems analysis research

The keyword co-occurrence network resulted in six thematic clusters, as shown in Fig. 2. By performing a comprehensive analysis of all keywords within each cluster and highlighting the top ten, the development of themes is tailored to encompass the entirety of the research focus areas, incorporating systems analysis to address environmental and societal challenges in Africa. The integration of the top ten keywords into the theme descriptions aims to provide a finer understanding of each cluster's focus within the broader context of sustainable development and systemic challenges in Africa. The study identified the specific system analysis methods employed in the top five papers most relevant to the theme of each cluster. These themes, articulated through the lens of systems analysis, underscore the interconnectedness of societal, environmental, and educational challenges in Africa. They advocate for integrated, evidence-based approaches to policy-making, environmental management, health care, education, and conservation, aiming to foster sustainable development and improve quality of life across the continent.

#### *5.1.1 Integrated health systems and community care in Sub-Saharan Africa (Cluster 1, red)*

Integrated health systems are essential to addressing the diverse healthcare needs of communities in sub-Saharan Africa. Systems analysis highlights the interplay between health system structures, service delivery, and community engagement, demonstrating the value of localized, context-specific approaches to improve health outcomes (Table 2).

#### *5.1.2 Governance, policy, and sustainable development dynamics in Africa (Cluster 2, Green)*

Governance and policy mechanisms underpin sustainable development in Africa, with systems analysis shedding light on the interactions among governments, actors, and value chains. Social network analysis and related approaches reveal how policies,

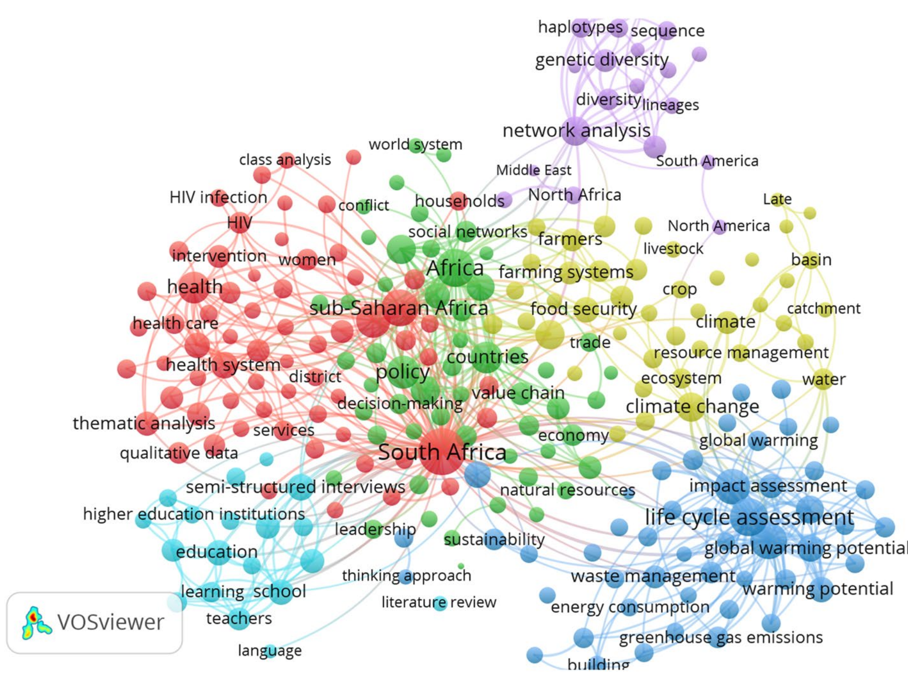


**Fig. 2** Thematic clusters based on systems analysis approaches

**Table 2** Top five system analysis papers relevant to the theme of Cluster 1

| Author(s) | Systems framework | Approach |
|---|---|---|
| Mutabazi et al. [63] | Complex adaptive systems framework | Analyzes Prevention of Mother-To-Child Transmission integration into primary health care in South Africa, focusing on system adaptability and response to socio-political challenges |
| Galle et al. [64] | Socio-Ecological Systems theory | Explores male involvement in maternal health in southern Mozambique, addressing systemic barriers and opportunities for enhancing participation at various system levels |
| Doherty et al. [65] | Health system dynamics framework | Assesses the impact of Prevention of Mother-To-Child Transmission policy implementation in Uganda, emphasizing the interaction between system components and the broader context |
| Ganle et al. [66] | Thematic network analysis framework | Understands decision-making processes affecting maternal health access in Ghana, analyzing complex systems through stakeholder interactions and social dynamics |
| Galle et al. [67] | Socio-ecological systems theory | Uses thematic analysis to examine barriers and facilitators of male involvement in maternal health in Mozambique, considering systemic factors at policy, community, and individual levels |

**Table 3** Top five system analysis papers relevant to the theme of Cluster 2

| Author(s) | Systems framework | Approach |
|---|---|---|
| Zwane [25] | System analysis and modeling | Investigates determinants of savings in South Africa using a two-stage least square estimation technique to model economic behaviors and their implications for growth and development |
| Lamboll et al. [68] | Complex adaptive systems framework | Analyzes the high-quality cassava flour value chain in Nigeria, focusing on uncertainty and adaptation strategies through system theory and dynamics |
| Gannan et al. [69] | Social life cycle assessment (Social LCA) | Examines the social dimension of sustainability in the African energy/bio-energy sector by assessing social impacts across the product life cycle |
| Li and Samimi [70] | System analysis and modeling | Develops a Sustainability Index and regression models to study the interconnections between migration and sustainable development in Sub-Saharan Africa |
| Kari & Mshelia [71] | System theory and digital era governance | Applies system theory and the Digital Era Governance model to analyze the role of digital technology in achieving sustainable development in Africa |

institutional dynamics, and actor networks influence progress toward the Sustainable Development Goals across African countries (Table 3).

#### *5.1.3 Environmental sustainability and impact assessments (Cluster 3, Blue)*

Life cycle assessment and environmental impact analysis are central to understanding sustainability challenges in Africa. Case studies on waste management, global warming potential, and other impact categories demonstrate how systems analysis supports effective environmental management. Evaluating the full life cycle of products and activities enables strategies to mitigate environmental degradation and advance sustainability goals (Table 4).

#### *5.1.4 Climate resilience, food security, and agricultural sustainability in Africa (Cluster 4, yellow)*

The nexus of climate resilience, food security, and sustainable agricultural practices is analyzed through systems approaches addressing the impacts of climate variability on farming systems, water resources, and smallholder livelihoods in West and East Africa. Studies emphasize adaptive and resilient farming strategies that sustain food security

**Table 4** Top five system analysis papers relevant to the theme of Cluster 3

| Author(s) | Systems framework | Approach |
|---|---|---|
| Yacout et al. [72] | Life cycle assessment (LCA) | Conducts cradle-to-gate LCA of acrylic fiber manufacturing in Africa and MENA, focusing on water, energy use, and waste generation |
| Lorenz et al. [73] | Life cycle assessment (LCA) | Assesses environmental impact of solar thermal power plants in South Africa, analyzing components, impact categories, and geographic variability |
| Adeleke et al. [74] | Life cycle assessment (LCA) | Performs comparative LCA of waste management systems in Johannesburg, focusing on unit processes and scenarios |
| Yacout et al. [75] | Life cycle assessment (LCA) | Models environmental performance of tilapia production in Egypt, comparing semi-intensive and intensive systems |
| Dunmade et al. [76] | Streamlined life cycle assessment | Identifies environmental impact hotspots in a coal-fired power plant in South Africa by analyzing the coal cycle |

**Table 5** Top five system analysis papers relevant to the theme of Cluster 4

| Author(s) | Systems framework | Approach |
|---|---|---|
| Kotir et al. [77] | System dynamics modeling | Develops a simulation model of interactions between population, water resources, and agriculture in the Volta River Basin for sustainable management |
| Paul et al. [78] | Farming systems modeling | Assesses impacts of improved livestock feeding and forages on reducing environmental trade-offs in East African smallholder farming systems |
| Masikati et al. [79] | Integrated assessment framework | Combines participatory methods with computer-based decision support tools to evaluate crop-livestock systems under climate change |
| Scholtz et al. [80] | Climate-smart systems thinking | Examines climate-smart livestock production technologies and feedback loops between livestock and climate change in South Africa |
| de Kinderen et al. [81] | Genotype × Environment interaction analysis | Predicts environmental effects on poultry breeds to optimize backyard poultry production in Oromia, Ethiopia |

and support smallholder farmers. Table 5 presents the top five papers and their systems analysis approaches.

#### 5.1.5 *Conservation, biodiversity, and genetic diversity (Cluster 5, purple)*

Systems analysis reveals how climate variability and change affect farming systems, water resources, and food security in West and East Africa, with particular attention to the livelihoods of smallholder farmers. Adaptive and resilient agricultural practices emerge as critical for sustaining food security under climate stress (Table 6).

#### 5.1.6 *Educational systems, theory, and pedagogical innovations in Africa (Cluster 6, magenta)*

Systems theory, particularly ecological systems theory, is applied to educational research and practice to analyze the complex dynamics of teaching and learning in African schools. Semi-structured interviews and other qualitative approaches reveal how pedagogical methods, school environments, and systemic factors shape teachers' effectiveness and students' learning experiences. These insights support innovative strategies to improve education across diverse contexts (Table 7).

### 5.2 Interdisciplinary research

To assess the interdisciplinary nature of African environmental and developmental research, the SDGs are employed as a measure because of their inherent requirement

**Table 6** Top five system analysis papers relevant to the theme of Cluster 5

| Author(s) | Systems Framework | Approach |
|---|---|---|
| Dehghani et al. [82] | Genetic and haplotype network analysis | Explores the diversity and distribution of *Echinococcus granulosus* in camels across the MENA region, identifying prevalent genotypes and their geographical variations |
| Nielsen et al. [83] | Network analysis and system modeling | Evaluates phylogenetic relationships and diversification patterns of *Breviceps* in sub-Saharan Africa, showing the influence of geomorphology and climate on biodiversity |
| Bhattacharjee et al. [84] | Network analysis and system modeling | Assesses genetic diversity and population structure in white yam across West Africa, revealing biodiversity patterns shaped by domestication and trade |
| Langat et al. [85] | Population genetics and haplotype network analysis | Investigates HBV genetic diversity in Kenyan blood donors, demonstrating how systems analysis informs disease management strategies |
| Sahu et al. [86] | Systems analysis of viral evolution | Studies the genetic diversity and evolution of Peste des petits ruminants virus in Africa, highlighting its impact on disease progression in small ruminants |

**Table 7** Top five system analysis papers relevant to the theme of Cluster 6

| Author(s) | Systems framework | Approach |
|---|---|---|
| Kumanda et al. [87] | Ecological systems theory | Examines environmental factors influencing the teaching of Natural Sciences to isiXhosa speakers in South Africa, suggesting a systemic perspective on educational challenges |
| Phala & Hugo [88] | Ecological systems theory | Analyzes how policies and school environments shape reading skills development in South Africa, applying a systemic lens to educational dynamics |
| Abongdia et al. [89] | Ecological systems theory, social constructivism, field theory | Identifies learning barriers through a systemic and socio-constructivist examination of educational inclusion in South Africa |
| Mahlo & Hugo [90] | Ecological systems theory | Investigates systemic factors influencing the implementation of Inclusive Education in South Africa, assessing the effectiveness of support structures |
| Mather et al. [91] | Technology acceptability model | Analyzes student adoption of ICT in South Africa, interpreted as a systems approach to user interaction within technological and educational contexts |

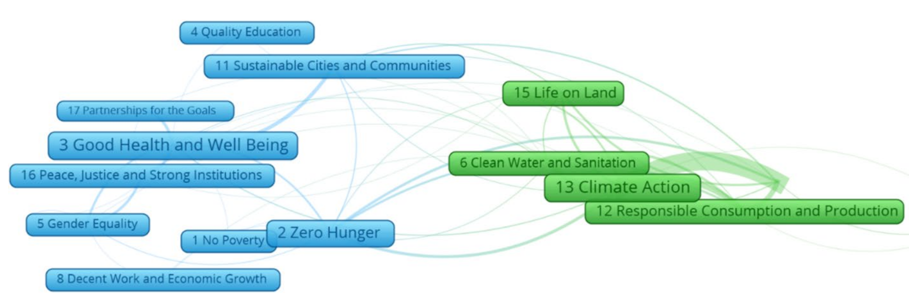


**Fig. 3** Interdisciplinary research as measured by a network of SDGs

for a collaborative approach that spans various academic domains, such as economics, environmental science, and social sciences.

In the SDG cocitation network (Fig. 3), we observe two primary clusters of research influence, distinguished by citation counts. The 'Green' cluster is influenced predominantly by SDG 13 (climate action) and SDG 15 (life on land), with SDG 12 (responsible consumption and production), as well as SDGs 6, 14, and 9, forming an interconnected research community focused on environmental and sustainability issues. The 'Blue' cluster is directed by SDG 3 (good health and well-being) and encompasses SDGs 1 (no poverty), 4 (quality education), 8 (cent work and economic growth), 16 (peace, justice and strong institutions), and 9 (industry, innovation, and infrastructure). This delineation suggests a collective of research that is pivotal to human and societal well-being, as well as infrastructural development.

In the context of systems analysis applied to environmental and societal challenges in Africa, the network visualization map highlights how research influence varies across different SDGs (Fig. 4). High citation rates for SDGs 1 (No Poverty), 6 (Clean Water and Sanitation), and 12 (Responsible Consumption and Production) suggest that these areas are central in the systems analysis discourse within Africa. This prominence may reflect research efforts focused on critical issues such as poverty alleviation, water management, and sustainable economic practices, which are particularly salient for the continent's environmental and developmental strategies.

SDG 3 (good health and well-being) occupies a central node within the network. This positioning of the SDG suggests that health and well-being are pivotal considerations and are integrally connected to other research areas within the systems analysis framework. The citation impact of SDG 3, while not the highest, is substantial and reflects its importance in the interconnected web of sustainability challenges. Research in this area is critical, particularly in the African context, where public health issues intersect with environmental and developmental factors, necessitating a systems-based approach to crafting holistic and sustainable solutions. Conversely, SDGs 4 (Quality Education), 8 (Decent Work and Economic Growth), and 10 (Reduced Inequalities) have lower citation impacts, indicating that these areas might be less emphasized in the systems analysis research landscape within Africa. This could signal a need for increased scholarly and policy focus, given that education, economic growth, and inequality are crucial for the continent's holistic development and integral to the systems approach.

### *5.2.1 Mapping to SDGs*

Table 8 presents the distribution of research publications mapped to various SDGs. The analysis reveals that SDG 3, "good health and well-being," garners the highest attention, with 295 publications and 4877 citations, suggesting a significant research focus and impact within this area. This prominence aligns with RQ1 and indicates a robust scholarly emphasis on health in the African context, which may reflect the pressing health challenges the continent faces. SDG 13, "Climate Action," follows closely in terms of citations, with 189 publications accumulating 3578 citations. This indicates a high

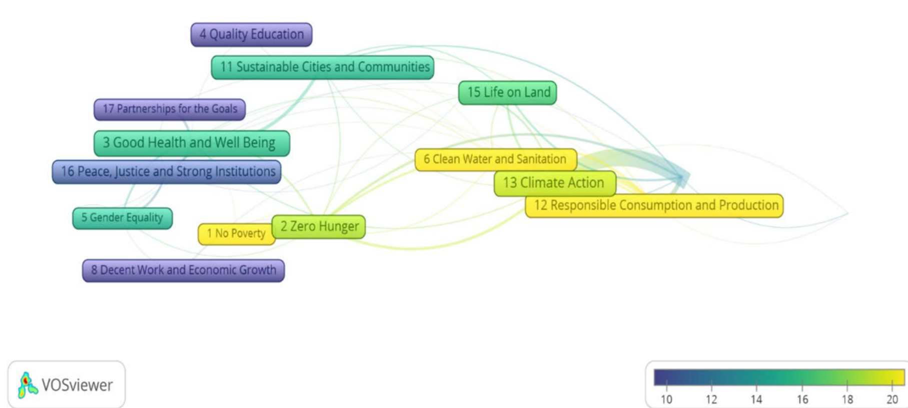


**Fig. 4** Research influence as measured by a network of SDGs

**Table 8** Research publications mapped to sustainable development goals

| SDG | Publications | Citations |
|---|---|---|
| 3 GOOD HEALTH AND WELL-BEING | 295 | 4877 |
| 13 CLIMATE ACTION | 189 | 3578 |
| 7 AFFORDABLE AND CLEAN ENERGY | 155 | 1998 |
| 2 ZERO HUNGER | 112 | 2074 |
| 15 LIFE ON LAND | 101 | 1648 |
| 16 PEACE, JUSTICE AND STRONG INSTITUTIONS | 84 | 911 |
| 4 QUALITY EDUCATION | 77 | 334 |
| 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | 72 | 1571 |
| 11 SUSTAINABLE CITIES AND COMMUNITIES | 71 | 1073 |
| 6 CLEAN WATER AND SANITATION | 49 | 993 |
| 8 DECENT WORK AND ECONOMIC GROWTH | 31 | 259 |
| 14 LIFE BELOW WATER | 22 | 304 |
| 5 GENDER EQUALITY | 19 | 284 |
| 10 REDUCED INEQUALITIES | 18 | 160 |
| 1 NO POVERTY | 12 | 251 |
| 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | 9 | 113 |
| 17 PARTNERSHIPS FOR THE GOALS | 9 | 51 |

level of academic engagement and influence, resonates with Africa's urgent need for climate change mitigation and adaptation strategies, and provides insight into the association of the SDGs with highly cited works. The third most cited SDG is 7, "Affordable and Clean Energy," with fewer publications (155) than SDG 13 but still a considerable citation count (1998). An interest in clean energy research is essential for a continent where energy access and sustainability are critical issues, which inquiries about research hotspots. Conversely, SDGs 9, "Industry, Innovation, and Infrastructure," and 17, "Partnerships for the Goals," receive the least attention, with 9 publications each, aligning with RQ1's investigation of the least emphasized goals. This suggests potential areas for increased research and strategic focus, especially given the critical role of innovation and partnerships in achieving sustainable development.

The distribution of publications on SDGs seems uneven, with the bulk of research concentrated on a few SDGs. This could imply a need for more balanced research efforts across all SDGs to ensure holistic environmental and developmental progress. In summary, Table 8 provides a valuable macroscopic view of the current research landscape, reflecting both strengths in certain areas and gaps in others, which can inform future research directions, policymaking, and funding allocation for addressing environmental challenges in Africa.

#### *5.2.2 Major topics*

In this section, we discuss a selection of representative publications within each major topic identified through BERTopic modeling. (Table 9).

## 6 Maternal health in sub-Saharan Africa

Galle et al. [64] explored the crucial yet under addressed aspect of male involvement in maternal health in southern Mozambique, highlighting systemic gaps in policy and practice. Their qualitative study, which was grounded in socioecological systems theory, revealed barriers such as social norms and the stigma associated with male participation in antenatal care (ANC). Addressing these challenges through a multilevel approach and promoting gender-equitable relationships can significantly improve maternal health outcomes. This research aligns with SDG3 (Good Health and Well-being) by emphasizing maternal health and intersects with SDG5 (Gender Equality) and SDG10 (Reduced Inequalities), highlighting the importance of inclusive health strategies within the broader context of systems analysis for environmental challenges in Africa.

**Table 9** Major topics, representative publications, and SDG focus

| Topic name | Representative publications | SDG focus |
|---|---|---|
| Maternal health in sub-saharan Africa | Galle et al. [64], Mutabazi et al. [63], Cowan et al. [92] | 3 GOOD HEALTH AND WELL-BEING<br>5 GENDER EQUALITY<br>10 REDUCED INEQUALITIES |
| Coastal Governance and Climate Resilience | Rölfer et al. [93], Nicolay et al. [94], Olabisi et al. [95] | 2 ZERO HUNGER<br>11 SUSTAINABLE CITIES AND COMMUNITIES<br>13 CLIMATE ACTION<br>15 LIFE ON LAND |
| Water Sustainability in Border Regions | Hargrove et al. [96], Mannsachatz et al. [97], Dlamini et al. [98] | 2 ZERO HUNGER<br>6 CLEAN WATER AND SANITATION<br>11 SUSTAINABLE CITIES AND COMMUNITIES<br>13 CLIMATE ACTION |
| Renewable energy development in Africa | Makarichev et al. [99], Musonye et al. [100], Jeged et al. [101] | 7 AFFORDABLE AND CLEAN ENERGY<br>9 INDUSTRY, INNOVATION AND INFRASTRUCTURE<br>11 SUSTAINABLE CITIES AND COMMUNITIES<br>13 CLIMATE ACTION |

To investigate the integration of the prevention of mother–child transmission (PMTCT) of HIV into primary healthcare services in South Africa, Mutabazi et al. [63] utilized a complex adaptive systems framework. This qualitative study highlights the significant strides made in maternal health, aligning with SDG3 goals by reducing HIV transmission rates and child mortality. This study underscores the challenges and barriers faced in fully integrating PMTCT into primary healthcare, suggesting improvements for broader health service integration to enhance maternal and child health outcomes in the African context.

In their 2015 study, Cowan et al. explored the implementation of the World Health Organization's "Option B + " strategy in Mozambique for preventing mother–child transmission (MTCT) of HIV. This strategy involves the immediate initiation of antiretroviral therapy (ART) for HIV-positive pregnant women. Research employing a stepped wedge randomized controlled trial aims to increase ART initiation before delivery and improve care retention. This study's findings contribute to addressing SDG3 goals by enhancing maternal health services and reducing HIV transmission rates, reflecting the broader theme of systems analysis in tackling environmental and health challenges in Africa.

## 7 Coastal governance and climate resilience

With respect to the mechanisms by which coastal governance enhances climate resilience in Algoa Bay, South Africa, Rölfer et al. [93] combined stakeholder and social network analysis. This research underscores the necessity for both top-down and bottom-up approaches in improving knowledge exchange and stakeholder engagement in coastal social-ecological systems (SESs). The study's recommendations for bolstering leadership, integrating climate information, and including marginalized voices align with the broader systems analysis framework for addressing environmental challenges in Africa, contributing to SDGs focused on SDG13 (climate action) and SDG11 (sustainable communities).

Nicolay et al. [94] present a case study on organic cotton in Mali, emphasizing the need for a new farming systems approach that integrates interdisciplinary systems thinking and participatory research to address sustainable agriculture. Their work, which focused on certified organic combined with agroecology, highlights the importance of providing societal support for extension, technology development, and policy coherence, particularly for family farms and small-scale entities. This study aligns with SDG15 (Life on Land) by proposing sustainable farming practices that mitigate environmental challenges, demonstrating the potential of systems analysis in enhancing agricultural sustainability and resilience in Africa.

A study by Olabisi et al. [95] explored the use of participatory system dynamics modeling to aid climate change adaptation in Nigeria's poultry sector. By engaging stakeholders in developing a model to assess climate impacts and adaptation strategies, this approach facilitates social learning and policy insight, directly contributing to SDG13 and SDG2 (Zero Hunger). The participatory modeling serves as a critical tool for integrating community-level priorities into national policy, highlighting the effectiveness of systems analysis in fostering adaptive governance and resilience in African agricultural systems amidst climate challenges.

## 8 Water sustainability in border regions

A key representative article on this topic is a system dynamics simulation model used by Hargrove et al. [96] to address sustainable water resource management and agricultural development in the Volta River Basin, Ghana. Their research, which focused on the interactions between population dynamics, water resources, and agricultural productivity, provides critical insights into the long-term sustainability of water use in the region. By developing and implementing various policy scenarios, this study highlights the effectiveness of water infrastructure development in enhancing food security, reducing poverty, and promoting socioeconomic growth, aligning with SDGs related to clean water and sanitation (SDG 6), zero hunger (SDG 2), and sustainable cities and communities (SDG 11). This work exemplifies the application of systems analysis in understanding and solving complex environmental challenges in African contexts, particularly emphasizing water sustainability in border regions.

Visualization techniques to support nexus governance are at the center of a study that focuses on improving water services in Africa, highlighting their role in facilitating integrated decision-making and resource management [97]. They address the spatial disparity of water resources and propose data collection and visualization methods for better water management. This research contributes to SDG6 by highlighting the importance of integrated approaches to water resource management, which is crucial for addressing water scarcity and quality issues in Africa.

Using the water–energy–food (WEF) nexus, Dlamini et al. [98] developed climate change adaptation strategies in South Africa's Buffalo River catchment. They assess the sustainability of policy plans under climate change conditions, emphasizing the need for equitable water distribution. This study supports SDG13 and SDG2 by proposing optimized policies for water resource management in the face of changing climate patterns.

## 9 Renewable energy development in Africa

A multifaceted approach was used to evaluate the sustainability of lignocellulosic bioenergy systems in South Africa, emphasizing environmental, social, and economic dimensions of bioenergy development [99]. Employing life cycle assessment, multicriteria decision analysis, and other tools, this study identifies a system comprising specific harvesting, transportation, and conversion technologies as the most sustainable for electricity generation. This research directly supports the SDGs related to affordable and clean energy (SDG 7) and climate action (SDG 13) by demonstrating a methodical way to select renewable energy systems that balance environmental, economic, and social factors, which is crucial for addressing environmental challenges and promoting renewable energy development in Africa.

A comprehensive review of integrated energy systems modeling studies for Sub-Saharan Africa highlights both the region's persistent energy poverty and the potential role of renewable energy resources in addressing it [100]. Their analysis stresses the importance of decentralized generation, grid extension, and the adoption of hybrid approaches to address the complex interplay of economic, energy, and environmental challenges. This work aligns with SDGs focused on affordable and clean energy (SDG 7), industry, innovation, and infrastructure (SDG 9), and sustainable cities and communities (SDG 11), offering a pathway toward renewable energy development in Africa that leverages systems analysis for strategic planning and capacity building.

The study by Jegede et al. [101] focuses on the optimal design of islanded distributed energy systems incorporating renewable energy for rural Africa, using a case study in Namibia. The study advocates a hybrid energy system approach, considering the logistical and cost challenges of fuel supply and the benefits of local renewable resources. This approach is instrumental in advancing the SDGs related to affordable and clean energy (SDG 7), reduced inequalities (SDG 10), and sustainable cities and communities (SDG 11) by providing a model for designing renewable energy systems that address the specific needs and challenges of rural African communities, thereby contributing to the broader theme of systems analysis for environmental challenges.

### 9.1 Funding SDG research

Table 10, which outlines the top ten funders of research on the basis of publications and citations, becomes particularly revealing in the context of recent discussions at the UN SDG Summit 2023 [102]. The National Research Foundation of South Africa leads in the number of publications, while funding entities from Belgium, the United States, and the United Kingdom also feature prominently. This distribution of funding highlights the disparities and challenges that were emphasized at the summit, where urgent calls were made for increased and equitable investment in SDG-related research and development, particularly for African nations.

From the data, we can infer a global perspective on research interests and investments in African sustainable development. Organizations from the Global North, such as those in the United States, Belgium, and the United Kingdom, show substantial involvement in African research, which is reflected in their high number of funded publications and citations. The diversity of SDG focuses suggests that while some funders concentrate on specific goals such as SDG 3 (good health and well-being) or SDG 7 (affordable and clean energy), others take a broader approach by supporting research across multiple SDGs.

Interestingly, the Table 10 hints at an imbalance in research funding and focus between the Global North and South, with organizations from the Global North potentially exerting greater influence on the direction of African SDG-related research. This could be due to greater financial capabilities and strategic interests in certain development areas. The presence of the National Research Foundation of South Africa as a significant funder indicates active local investment in sustainable development research. Furthermore, the SDG focus reflects the priorities of different funders; for instance, health and well-being are prominent, possibly because of the urgent global health issues impacting Africa. The emphasis on SDG 13 (climate action) suggests a growing recognition of the critical need for climate-related research in Africa.

## 10 Discussion

Systems analysis in SDG research (RQ1) highlights how governance, environmental sustainability, health, education, and resource management are interconnected in Africa (Fig. 5). Research on local health system governance has demonstrated how collaborative action is crucial in addressing complex health challenges within the SDG framework, emphasizing the interplay between governance and health systems [103]. Additionally, prioritizing health information systems and governance structures has been identified as essential in achieving SDG 3 and other interconnected targets, further underscoring

**Table 10** Major funders of research, according to publications

| Name | Country | Publications | Citations | SDG focus |
|---|---|---|---|---|
| National research foundation (NRF) | South Africa | 77 | 1221 | 15 LIFE ON LAND<br>3 GOOD HEALTH AND WELL-BEING<br>13 CLIMATE ACTION |
| European commission (EC) | Belgium | 51 | 1370 | 13 CLIMATE ACTION<br>3 GOOD HEALTH AND WELL-BEING<br>7 AFFORDABLE AND CLEAN ENERGY |
| National institute of allergy and infectious diseases (NIAID) | United States | 31 | 846 | 3 GOOD HEALTH AND WELL-BEING |
| Bill & Melinda gates foundation (BMGF) | United States | 26 | 1115 | 3 GOOD HEALTH AND WELL-BEING<br>7 AFFORDABLE AND CLEAN ENERGY<br>2 ZERO HUNGER |
| National natural science foundation of China (NSFC) | China | 26 | 844 | 3 GOOD HEALTH AND WELL-BEING<br>13 CLIMATE ACTION<br>7 AFFORDABLE AND CLEAN ENERGY |
| Wellcome trust (WT) | United Kingdom | 22 | 588 | 3 GOOD HEALTH AND WELL-BEING<br>2 ZERO HUNGER |
| South African medical research council (SAMRC) | South Africa | 18 | 254 | 3 GOOD HEALTH AND WELL-BEING |
| United States Agency for international development (USAID) | United States | 18 | 318 | 3 GOOD HEALTH AND WELL-BEING<br>13 CLIMATE ACTION<br>2 ZERO HUNGER |
| Economic and social research council (ESRC) | United Kingdom | 17 | 369 | 3 GOOD HEALTH AND WELL-BEING |
| National institute of mental health (NIMH) | United States | 16 | 297 | 3 GOOD HEALTH AND WELL-BEING |

the systemic relationships among different sectors [104]. Governance plays a crucial role in shaping policies that affect SDG 3 (Good Health and Well-being), SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 15 (Life on Land). However, weak policy coordination leads to inefficiencies in public services and environmental protection. Fragmented health systems in sub-Saharan Africa struggle to integrate community healthcare initiatives with national policies, limiting progress toward universal health coverage. The lack of integration between community healthcare services and broader national health policies has been identified as a major barrier to sustainable healthcare delivery, affecting efforts to achieve universal health coverage [105]. The application of


**Fig. 5** Systems analysis research for sustainable development in Africa

a complex adaptive systems framework has been instrumental in analyzing healthcare system adaptability and responses to sociopolitical challenges [63], whereas socioecological systems theory has been used to examine male involvement in maternal health [64, 67]. Without stronger governance mechanisms, achieving sustainable development goals remains difficult.

Sustainable resource management (SDG 12) and climate action (SDG 13) depend on environmental assessments and life cycle analyses, yet their effectiveness in Africa is hindered by weak regulatory enforcement. Waste management and pollution control remain inconsistent, with informal recycling systems playing a significant role where formal regulations are absent. A historical review of waste management in South Africa highlights how inadequate policy enforcement and fragmented regulatory frameworks have limited the success of sustainable waste management practices, reinforcing the reliance on informal recycling sectors to fill the gaps left by weak governance [106]. The application of life cycle assessment (LCA) to waste management systems and industrial production processes [72, 74, 75] highlights how systems analysis can inform sustainability transitions. In agriculture (SDG 2), smallholder farmers dominate food production but often lack access to the technology and infrastructure needed for climate-smart farming. The adoption of efficient irrigation, sustainable land use, and resilient crop varieties is limited due to weak policy support and financing constraints. Addressing these gaps through stronger governance and investment in agricultural innovation is crucial for enhancing food security [107] and adapting to climate change. System dynamics simulation models have been used to study the interactions among population growth, water resources, and agricultural production, providing insights into sustainable management strategies [77]. A review of climate change policies in 16 West African countries highlights how inadequate policy frameworks and insufficient financial mechanisms hinder the adoption of sustainable agricultural practices, emphasizing the need for stronger institutional support and targeted investments to enhance resilience and food security [108].

Health (SDG 3) and education (SDG 4) function within broader socioeconomic systems where access, infrastructure, and policy coherence are critical. Community-led healthcare initiatives help bridge service gaps, but their impact is restricted when they are not integrated into national health strategies. Education in Africa faces persistent challenges such as underfunded schools, teacher shortages, and disparities in digital access. Many rural schools rely heavily on community involvement, yet this alone is not enough to close learning gaps (Muremela et al., 2021). Additionally, efforts to integrate digital learning tools in Sub-Saharan African schools have been hindered by insufficient funding and limited teacher training, further widening the urban–rural divide in education accessibility [109]. The use of ecological systems theory in analyzing educational challenges [87, 88] highlights how systemic factors shape learning environments. Urban students benefit from digital learning tools, whereas rural areas lack reliable infrastructure. Strengthening governance in these sectors, including investments in digital education and teacher training, is essential for reducing inequalities (SDG 10) and ensuring inclusive learning opportunities.

Climate resilience (SDG 13) and food security (SDG 2) are also deeply interconnected. Smallholder farmers across Africa rely on traditional knowledge to adapt to climate variability, yet the lack of predictive analytics and policy support limits their resilience. Integrating indigenous practices with modern climate adaptation tools is crucial for sustainability [110]. Conservation and biodiversity protection (SDG 15) are similarly constrained by governance gaps. Despite rich biodiversity, many African countries struggle with enforcement due to limited funding and competing economic priorities. Deforestation, illegal logging, and weak regulations threaten ecosystems and endangered species, underscoring the need for stronger conservation efforts [9]. Network analysis and genetic diversity assessments have been applied to understand species conservation [82, 84], offering insights into ecosystem resilience. Across all these domains, fragmented governance, poor cross-sector coordination, and resource disparities hinder progress. Achieving SDG 16 (Peace, Justice, and Strong Institutions) is essential for ensuring more effective policies and regulatory frameworks that support sustainable development. Stronger regional cooperation, participatory governance, and interdisciplinary approaches are needed to align economic and environmental priorities. By integrating governance reforms, technology-driven solutions, and community-led initiatives, African nations can build resilience, promote inclusive development, and advance progress across multiple SDGs.

Interdisciplinary approaches to sustainable development in Africa (RQ2), guided by the SDG framework, demonstrate varying levels of integration across sectors, highlighting both contributions to global sustainability goals and knowledge gaps that require further exploration (Fig. 6). The four major topics identified through BERTopic modeling—maternal health, coastal governance and climate resilience, water sustainability, and renewable energy—reflect the continent's unique socioenvironmental challenges and

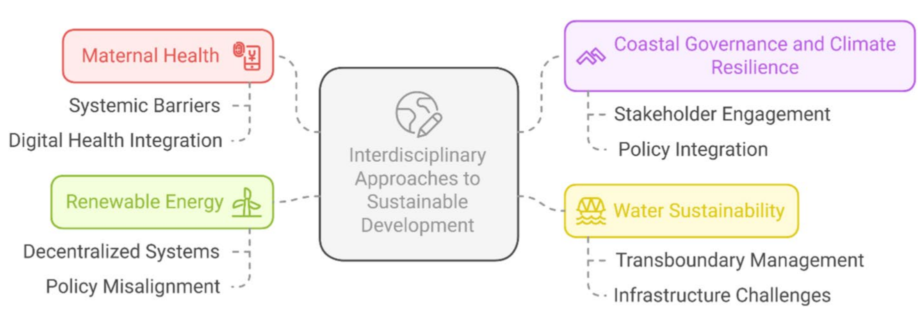


**Fig. 6** Interdisciplinary approaches to sustainable development in Africa

how systems analysis facilitates research across these domains. Maternal health research in sub-Saharan Africa aligns with SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), and SDG 10 (Reduced Inequalities), emphasizing the systemic barriers to healthcare access, policy implementation, and community engagement. While studies address issues such as male involvement in maternal health and HIV prevention, gaps remain in integrating digital health strategies, telemedicine, and AI-driven diagnostics. Research highlights challenges in implementing telemedicine programs in sub-Saharan Africa, including financial, regulatory, and technological barriers [111]. Additionally, digital health interventions for maternal care face accessibility and inclusion issues, underscoring the need for more comprehensive strategies [112]. Coastal governance [113] and climate resilience [114] research, linked to SDG 13 (climate action) and SDG 11 (sustainable cities and communities), highlights the importance of stakeholder engagement in managing coastal resources and mitigating climate risks. Africa's reliance on participatory governance models contrasts with the centralized approaches seen in other regions, where regulatory frameworks and predictive modeling tools play a greater role. Research gaps exist in bridging local governance with national policy initiatives and integrating advanced climate data analytics to enhance resilience planning.

Water sustainability in border regions is a recurring research theme aligned with SDG 6 (Clean Water and Sanitation) and SDG 2 (Zero Hunger). Studies emphasize the importance of transboundary water management, participatory decision-making, and integrated resource planning. Unlike high-income regions with extensive water security infrastructure, Africa faces significant challenges in terms of accessibility, infrastructure investment, and policy coordination across borders. Weak governance and fragmented adaptation strategies hinder efforts to ensure climate-resilient water management [8]. Additionally, gaps in water security policies, as seen in postapartheid South Africa, highlight the need for stronger investment and coordination mechanisms to achieve equitable water distribution [115]. Renewable energy development, central to SDG 7 (Affordable and Clean Energy) and SDG 9 (Industry, Innovation, and Infrastructure), is a key research area, with studies focusing on decentralized energy systems, bioenergy, and hybrid renewable energy solutions. Compared with developed regions where energy transition policies are well established, Africa's energy sector still faces limited infrastructure, investment challenges, and policy misalignment. Gaps persist in scaling renewable energy solutions for rural electrification, integrating energy storage, and developing region-specific regulatory frameworks. Off-grid mini-grids face challenges in terms of reliability and scalability, highlighting the need for improved storage solutions [116, 117]. Additionally, weak regulatory frameworks hinder electrification efforts, emphasizing the urgency of tailored policies to accelerate energy transitions [118]. Across all four topics, Africa's interdisciplinary research contributes to the SDGs by applying systems analysis to complex socioenvironmental problems, yet knowledge gaps persist in leveraging technological innovations, fostering policy coherence, and improving cross-sectoral collaboration. Strengthening interdisciplinary approaches with insights from comparative global studies, digital transformation, and localized implementation strategies can enhance the continent's progress toward sustainable development.

As seen in Fig. 7, this study examines the role of funding in shaping African environmental research (RQ3) and its alignment with the SDGs, particularly those related to clean water (SDG 6), affordable energy (SDG 7), and climate action (SDG 13). In Africa,

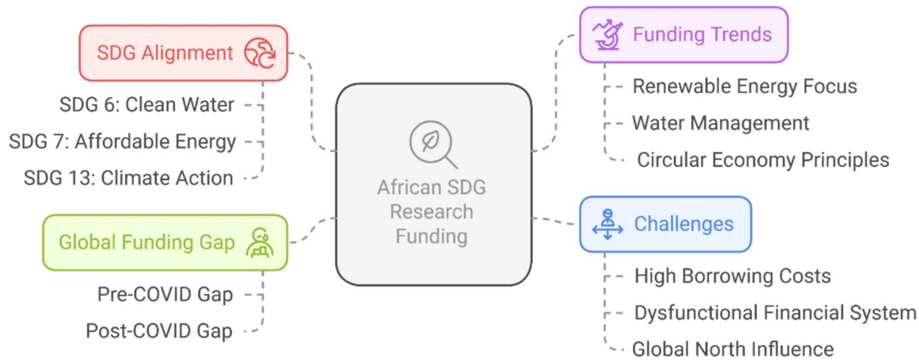


**Fig. 7** African SDG research funding

current funding trends have driven a concentration of research on renewable energy, water management, and circular economy principles, reflecting the global urgency of these challenges. However, this has led to disparities in resource allocation, with under-represented SDGs such as health (SDG 3), education (SDG 4), and gender equality (SDG 5) receiving significantly less funding [119, 120]. Research highlights how investments remain skewed toward sustainable development projects, whereas critical social sectors lack adequate support, underscoring the need for more inclusive and balanced funding mechanisms [121]. This imbalance calls for a strategic redirection of research agendas and financing to ensure a holistic approach toward achieving all the SDGs. Recent analyses have revealed an escalating global funding gap of approximately $4.2 trillion annually for achieving the SDGs, which is significantly greater than the $2.5 trillion gap identified before the COVID-19 pandemic. The 2023 UN SDG Summit emphasized the critical need for systemic reforms in the international financial architecture to address these deficits. African nations, in particular, face severe financial challenges due to exorbitant borrowing costs and a dysfunctional global financial system, which limits their capacity to mobilize resources for SDG progress [122, 123]. This disparity highlights the influence of Global North organizations in shaping African research priorities and the need for more balanced, locally driven research agendas.

### 10.1 Implications for policy

The study findings highlight policy priorities for aligning sustainable development efforts in Africa with the SDGs. Strengthening health systems (SDG 3, SDG 5) requires policies that integrate maternal health programs, improve primary healthcare access, and address gender disparities in healthcare participation. Governance and policy mechanisms (SDG 16, SDG 17) should promote participatory decision-making, enhance transparency, and support multisectoral partnerships for sustainable resource management. Environmental sustainability and impact assessment policies (SDG 12, SDG 6) should incorporate life cycle assessment tools, strengthen waste management frameworks, and improve transboundary water governance. Climate resilience and food security policies (SDG 13, SDG 2) must focus on climate-adaptive farming, infrastructure investments, and financial support for smallholder farmers. Conservation policies (SDG 15, SDG 14) should enforce sustainable land-use practices, strengthen biodiversity monitoring, and expand marine conservation programs. Education policies (SDG 4) should enhance teacher training, expand digital learning, and align vocational education with sustainable development priorities. Maternal health policies should expand HIV prevention programs and eliminate barriers to antenatal care. Coastal governance policies must integrate climate data into planning and improve stakeholder collaboration. Water sustainability policies should increase infrastructure investments and transboundary cooperation. Renewable energy policies (SDG 7, SDG 9) should promote decentralized energy systems, incentivize clean energy investment, and expand rural electrification. Addressing Africa's financial constraints requires aligning policies with global financing mechanisms to ensure equitable funding distribution and data-driven decision-making. Cross-sector collaboration and targeted investment will enhance policy effectiveness, supporting Africa's progress toward the SDGs.

Funding disparities could be mitigated through African Union–led initiatives like expanding the Science, Technology and Innovation Strategy for Africa (STISA-2024), establishing African Union–managed SDG research funds, and promoting south–south collaboration, ensuring investments align with regional priorities and reduce dependence on Global North funders.

A notable limitation of this study is the structural barriers that restrict the ability of African-based researchers to publish in international journals. Factors such as high publication fees, limited research funding, and heavy teaching workloads reduce the time available for research and scholarly dissemination. As a result, many locally conducted scientific studies, including policy briefs, dissertations, and institutional reports, remain outside the scope of standard literature searches. This creates a bias toward publications authored by non-African researchers or Africans affiliated with institutions outside the continent. The reliance on specific databases and methodologies, such as BERTopic modeling's sensitivity to hyperparameter choices, might have oversimplified the thematic areas identified, potentially overlooking emerging areas of research that are not yet well represented in the literature. The subjective aspect of theme and topic analysis could lead to biases, underscoring the need for verification by specialists. A limitation of studies employing SDG mappings lies in the varying algorithm databases used to map papers to SDGs, resulting in inconsistent mappings that can skew research insights and subsequent funding and policy directions [124]. While a detailed quantitative comparison was beyond the scope of this study, prior research has noted substantive variability between the two databases [125]. To ensure transparency and methodological consistency, Dimensions was chosen as the primary source for SDG mappings, given its documented classification framework and its explicit alignment with the United Nations SDG indicators through its open data initiatives. This choice is also consistent with earlier bibliometric analyses that have prioritized Dimensions for SDG-related research [126–128]. Additionally, relying on citation counts to gauge impact can skew our results due to inherent flaws in citation analysis, such as bias, the spread of misconceptions, a lack of critical viewpoints, and problems such as incorrect attribution or the layering effect of repeated citations [129, 130]. Moreover, this approach tends to disadvantage non-English and locally published research, potentially underrepresenting context-specific insights and regional knowledge.

### 10.2 Future research directions

Future research should examine how systems-based approaches can improve policy coordination, stakeholder engagement, and implementation strategies across key development sectors in Africa and the broader Global South, aligning with SDG 16 (Peace, Justice, and Strong Institutions) by strengthening governance frameworks and institutional capacity. Studies on health systems (SDG 3: Good Health and Well-being) should explore the long-term impacts of integrating community-based care models and digital health interventions, particularly in resource-constrained settings where healthcare access remains a challenge.

Environmental sustainability studies can expand impact assessments by incorporating SDG 12 (Responsible Consumption and Production) and SDG 6 (Clean Water and Sanitation), which focus on scalable waste management strategies and sustainable water resource management tailored to urban and rural contexts. Climate resilience research (SDG 13: Climate Action) should further investigate adaptive agricultural practices, transboundary water governance, and the effectiveness of nature-based solutions in mitigating climate risk, considering how smallholder farmers in Africa can build resilience under changing climatic conditions. Conservation research should integrate ecological modeling, policy analysis, and community-led initiatives to address biodiversity loss and habitat degradation, directly contributing to SDG 15 (life on land) and SDG 14 (life below water). Education research should explore how systemic reforms in curriculum design, teacher training, and digital learning can improve educational outcomes and workforce readiness, aligning with SDG 4 (quality education) to equip younger populations with relevant skills for sustainable development.

Future research on SDG funding should explore strategies for enhancing equitable investment in African research, particularly from regional and local funding bodies, to reduce dependence on Global North entities. Investigating the impact of funding distribution on research priorities can provide insights into how financial mechanisms shape SDG focus areas, particularly underfunded goals like SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities). Additionally, comparative analyses of funding models between Global North and South institutions could highlight the best practices for fostering sustainable and independent research ecosystems. Research should also focus on the potential of carbon finance, carbon credits, and green finance in supporting SDG-related initiatives. Assessing how these financial instruments can incentivize sustainable practices, enhance climate resilience, and contribute to SDG 13 and SDG 7 (Affordable and Clean Energy) is essential. Thematic clusters and funding trends from this study can guide future research by highlighting gaps, aligning priorities with SDG targets, and supporting evidence-based, systems-focused interventions.

## 11 Conclusion

This study demonstrates how systems analysis contributes to understanding and advancing sustainable development in Africa by identifying thematic priorities, interdisciplinary connections, and funding patterns aligned with the United Nations Sustainable Development Goals (SDGs). The findings show a concentration of research efforts on SDG 3 (*Good Health and Well-being*), SDG 7 (*Affordable and Clean Energy*), SDG 6 (*Clean Water and Sanitation*), SDG 13 (*Climate Action*), and SDG 15 (*Life on Land*), reflecting the continent's most urgent challenges. However, SDG 4 (*Quality Education*), SDG 10 (*Reduced Inequalities*), and SDG 16 (*Peace, Justice and Strong Institutions*) remain underrepresented, highlighting the need for broader systems-based approaches to address social and institutional dimensions of sustainability.

The analysis of interdisciplinary linkages reveals that African research tends to cluster around climate–urban (SDG 11 and SDG 13) and health–gender (SDG 3 and SDG 5) synergies, but less integration is seen across other goals. Systems analysis uncovers how these issues are interconnected, emphasizing that progress in one area can generate co-benefits in others, while gaps in governance and policy coherence impede holistic development. Weak institutional capacity and fragmented implementation limit the effectiveness of interventions designed to meet goals such as SDG 2 (*Zero Hunger*), SDG 4, and SDG 16. Addressing these gaps requires strengthening governance frameworks and ensuring participatory decision-making.

Funding patterns are heavily skewed toward SDG 7, SDG 6, and SDG 13, with less investment directed at SDG 4, SDG 10, and SDG 9 (*Industry, Innovation and Infrastructure*). This imbalance suggests a need to align funding priorities more closely with local development needs and to build regional financing mechanisms that can reduce dependence on Global North funders. Expanding initiatives like the African Union's STISA-2024 and creating SDG-focused regional funds can help foster more balanced progress across all goals.

Future research should explore how systems-based approaches can improve coordination and stakeholder engagement to achieve SDG 16 and support institutional reforms. In health and education, research can examine how integrated care models and digital learning tools improve access and equity, contributing to SDG 3, SDG 4, and SDG 10. Environmental research can expand the application of life cycle assessments and nexus modeling to enhance water governance, waste management, and conservation, advancing SDG 6, SDG 12 (*Responsible Consumption and Production*), and SDG 15. The potential of carbon finance and innovative funding mechanisms to support SDG 7 and SDG 13 also merits further exploration. By identifying thematic clusters, gaps, and funding disparities, this study offers a roadmap for aligning future research and policy with Africa's sustainable development priorities. Strengthening systems thinking, governance, and interdisciplinary collaboration is essential for achieving progress across the full spectrum of SDGs and fostering inclusive, resilient development on the continent.

**Author contributions**
All authors equally contributed to original writing, editing and reviewing the manuscript.

**Data availability**
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethical approval and Consent to participate**
Prof. Walter Leal Filho declares they are an EiC of Discover Sustainability and confirms that they were not involved in the handling or decision-making of their own submission.

**Consent to publish**
Not applicable.

**Competing interest**
The authors declare no competing interests.

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