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REVIEW ARTICLE

Nexus approach and environmental resource governance in Sub-Saharan Africa: a systematic review

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Abstract

Sub-Saharan Africa (SSA) is replete with significant environmental resources including forests, water, land, and energy; although its transition to a bio-resource economy is yet to be actualized. Consequently, there are limited socio-economic gains from resource valorization. These challenges which stall progress towards the attainment of several interlinked sustainable development goals, are rooted, among others in resource governance defects. Furthermore, the persistence of knowledge fragmentation on resource governance shades possibilities for an in-depth theorizing of the nexus approach. In this light, two questions beg for answers: (i) To what extent are governance indicators captured in empirical studies on the nexus approach in SSA? (ii) What questions and approaches should inform future research on the nexus approach in SSA? To answer these questions, this paper systematically reviews 100 peer-reviewed articles (with 154 cases) that address governance questions in nexus studies within the broad framework of bioeconomy transitioning in SSA. Using the PROFOR analytical framework, our analysis reveals the following: (1) Although sub-regional variations exist in the application of nexus thinking, the overall emphasis in SSA is on first-level resource transformation. (2) With only 5% of studies explicitly mentioning the nexus approach, there is a strong indication for nexus thinking to be prioritized in future research. (3) While efficiency is the most recurrent in the literature (69%), its assurance in resource nexus and transformation is insignificant. (4) Interlinked questions of equity, participation, transparency, and conflict management have not been sufficiently addressed in studies on the nexus approach. The paper suggests an urgent need for in-depth, multi-country, and interdisciplinary research on these governance parameters in the nexus approach, as prerequisite to advancing the science–policy intercourse in nexus thinking in SSA.

Keywords Environmental resources · Bioeconomy · Nexus approach · PROFOR · SSA · Research agenda

Introduction

Population growth is exerting significant pressure on the earth's finite environmental resources, forcing governments to search for approaches that guarantee sustainable resource use (Adekunle 2020). Growing unsustainable resource use and declining environmental quality remains a preoccupying global issue with several attendant effects, including food insecurity (IPCC 2014). Estimates show that if present rates of unsustainable resource use continue unchecked, its climate change cost could reach US $ 1 trillion annually by the year 2100 (Eliasch 2008). As the trend continues amidst rising poverty levels, loss of livelihoods and significant outmigration, global interests through "bioeconomy" approaches are gaining grounds under different governance settings (UNEP 2014). Such approaches are expected to create interdependent and synergistic resource production and transformation systems (Hülsmann and Jampani 2021). Scholars

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argue that one way to come out of this impending crisis is to instill nexus thinking in the extraction, production, transportation and processing of environmental resources (Barma et al. 2012; Ayee 2014; Nhamo et al. 2020). This craving for resource use efficiency is reflected in global commitments to achieve sustainability, and most especially in Africa's Agenda 2063. Specifically, the aspiration for a prosperous Africa based on inclusive growth and sustainable development (Aspiration 1) and an Africa of good governance—rooted in equity, justice and the rule of law (Aspiration 3), are primordial (African Union Commission 2015). In these, SSA has a major stake.

Current evidence reveals that SSA hosts some of the world's most valuable resources. Paradoxically, these resources have, in part, been the bane of her development, leading to a paradox of plenty (Humphreys et al. 2007; Barma et al. 2012; Hanson et al. 2014). Furthermore, SSA's economy contracted by 3% in 2020—indicating an over 5% drop in real per capita income, compared to 2013 levels (IMF 2020). This paradox is, at least, partially rooted in poor resource governance regimes that failed to address issues of accountability, transparency, participation and conflict management—thereby compromising sustainable resource management (Ayee 2014; Arthur 2014; Adekunle 2020). The paradox has seemingly assumed a perennial attribute, as resource conflicts, rather than resource transformation cases are on the rise. While global orientation towards bioeconomy transition has also introduced a new dynamic for SSA, there are justifiable concerns that the inherent governance problems incumbent in the extractive sector could further manifest in SSA's bioeconomy transition (Humphreys et al. 2007).

'Bioeconomy' denotes the knowledge-based use of biological resources, relying on innovations that link multiple economic sectors (Global Bioeconomy Summit 2015). The term encompasses sectors (industrial and economic) involved in producing, managing and exploiting biological resources, among others (European Commission 2012; Koukios 2014, 2015; Koukios et al. 2020). The core values of bioeconomy rests on the promotion of efficiency in resource transformation, and the derivation and equitable distribution of resource benefits, while sustainably managing natural resources (Koukios et al. 2020). Bioeconomic research has evolved as a distinct field which draws from several linked disciplines: In the 1970s, it denoted 'a new economic order', acknowledging the biological bases of most economic activities (Knierim et al. 2018). This field further evolved in a more transdisciplinary fashion, characterized by growing cooperation among scientists and practitioners. The three core traits of transdisciplinarity are viewed in bioeconomy's (1) acknowledgement of complex world problems—usually beyond the scope of a single discipline, (2) fostering synergy amongst scientists and development stakeholders, and (3) rolling-out more dynamic research methods (Zscheischler and Rogga 2015).

Despite the lack of consensus on its definition, scientists agree that a more systematic approach (e.g., nexus approach) is required to enhance bioeconomy transition (Pulzl et al. 2014). As with the bioeconomy concept, the nexus concept equally begs for a unifying definition (Endo et al. 2017). Currently, it is viewed as a generic-conceptual approach to explore interactions and processes within systems (e.g., environmental resource systems), and between multiple systems (Harry and Factor 2017; Hülsmann and Jampani 2021).

The nexus approach has gained widespread traction in the last decade, albeit with a slow evidence base for SSA. The approach is premised on the fact that environmental resource systems and their related sectors are inherently interlinked (Lautze 2020; Hülsmann and Jampani 2021). Therefore, a more holistic approach which recognizes such links is required in the pursuit of sustainable development. The approach demonstrates potentials to mitigate conflicts between different resource sectors. Bioeconomy sectors are networked through the nexus approach, offering a yet to be fully explored "Pandora's box" for innovation and synergy.

At the heart of the linking of natural resources and the enhancement of production, management, and exploitation (bioeconomy), that is, the nexus approach, is governance (Angenendt et al. 2018; Lewandowski et al. 2018). While bio-economic models present useful opportunities for countries in dire need of a transition, the governance mechanisms that shape this transition remain relatively less well understood. That is, how governance issues manifest in nexus thinking in the context of the bioeconomy, and the methodological approaches which have been employed so far to study these issues remain largely unconsolidated (Hülsmann and Jampani 2021; Kimengsi and Balgah 2021). This holds true for SSA—an environmental resource haven. The urgent need for a systematic review of the state-of-the-art is evident, to unbundle contemporary conceptual and methodological issues in nexus thinking. To stem this knowledge fragmentation, this article undertakes a review of 100 empirical works containing 154 case studies conducted so far, with a focus on governance attributes in resource production and transformation. Besides clarifying conceptual and methodological gaps, the review is relevant in the framing of forward-looking resource governance questions on the nexus approach, of particular relevance to SSA. The PROFOR[1] governance

[1] The Program on Forests (PROFOR) governance framework is an adaptable multi-indicator governance assessment tool which was developed by the FAO and the World's Bank's PROFOR (Cowling et al. 2014). It consists of a set of indicators which could be used to assess governance especially around natural resource extraction, production and transformation settings. For details, see; http://www.fao.org/climatechange/27526-0cc61ecc084048c7___a9425f64942df70a8.pdf.

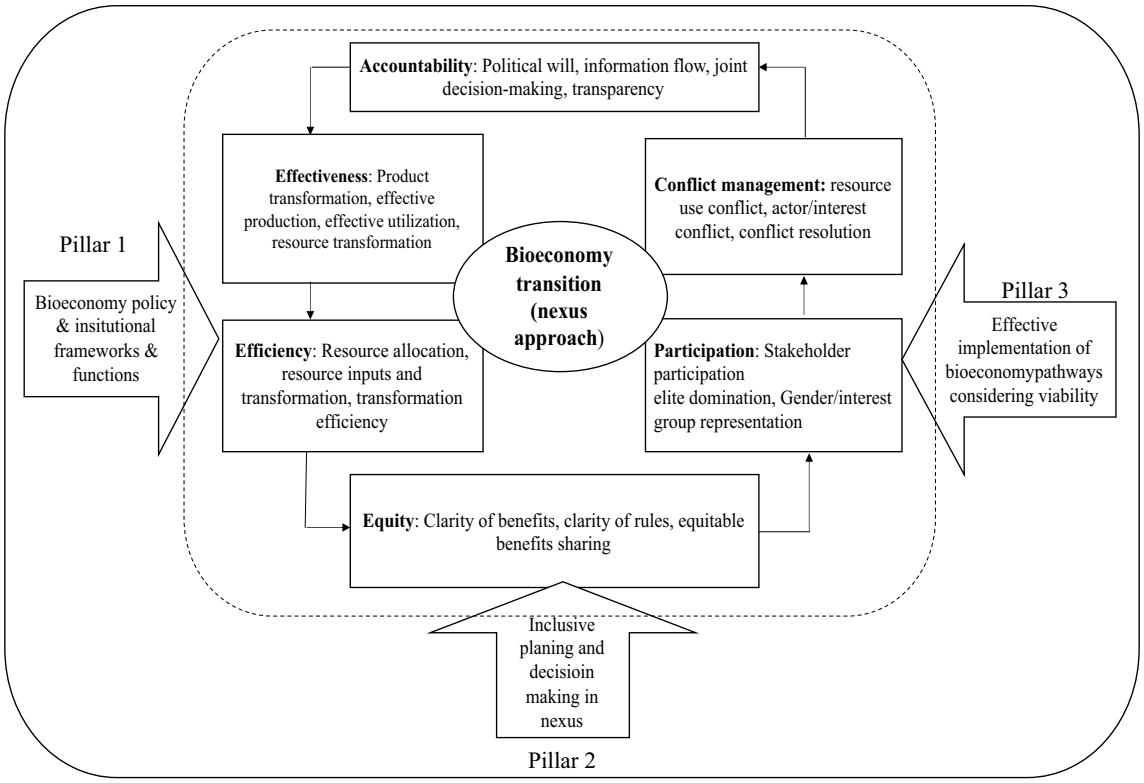

Fig. 1 Review analytical framework (modified from PROFOR/FAO (2011)

framework is employed as analytical lens in this case. The framework captures several governance indicators (e.g., accountability, effectiveness, efficiency, equity, participation, and transparency) which are globally relevant, but also applicable to SSA (Kimengsi and Bhusal 2021). Besides contributing to advance theoretical debates on environmental resource governance, the framework is policy relevant for natural resource-dependent regions (e.g., SSA).

Methodology

Analytical framework

This review is anchored on the PROFOR assessment framework (Fig. 1) (FAO 2011). The framework holds that the state of environmental resource governance is a function of several contextual and interactive dimensions. Rooted in the universally accepted tenets of good governance, it has been applied in several global contexts, including in SSA (e.g., Maidell et al. 2012; Piabuo et al. 2018; Kimengsi and Bhusal 2021), Asia (e.g., Chokkalingam and Phanvilay 2015; Kimengsi and Bhusal 2021), and Latin America (e.g., Campese et al. 2016). Furthermore, with a broad set of indicators, it touches on general and specific features of governance, while others serve as proxies for indicators that cannot be directly accessed (FAO 2011). Besides providing a good analytical lens to comprehensively understand governance, the tool also ushers in an opportunity for very convincing assessments which could shape future governance reforms in the spectrum of bioeconomy transition (Kishor and Rosenbaum 2017). In the context of the bioeconomy, reforms that promote nexus thinking constitute the policy, institutional and regulatory framework (Pillar 1). These reforms which are either at their budding phase or are yet to be effectively introduced in SSA, can potentially unravel multi-sectoral clashes (e.g., between the water and food sector, or the forestry and agricultural sector), while ensuring resource sector complementarity.

Besides assuring such thinking, practice also requires that effective transformation facilities should reduce perishability, add value to environmental resources, attract significant market benefits, and efficiently manage wastes. To ensure the effective mainstreaming of nexus thinking and practice, a more inclusive planning and decision-making process is required (Pillar 2). Despite the wishful thinking to accelerate bioeconomy transition, nations have to apply caution by ensuring congruence with the resource base, adopt appropriate technology and leverage capacity. Therefore, the viability of implementing the nexus concept in linked resource sectors should be effectively gauged (Pillar 3).

Table 1 Model coefficient estimates of the influence of sub-regions and years on the number of papers and case studies on environmental resource nexus in SSA

Models' parameters	Model 1	Model 2
Estimates (standard error)	1.237*** (0.142) $p=0.000$	1.844*** (0.271) $p=0.000$
F-statistic	0.468 $p=0.830$	0.827 $p=0.553$
Adjusted *R*-squared	− 0.043	− 0.137
Multiple *R*-squared	0.038	0.065

Values in parenthesis are the standard errors; levels of significance of coefficient. ***$p \leq 0.01$, **$p \leq 0.05$, *$p \leq 0.10$, where p is the alpha level

Within these pillars, we identified a number of review indicators. These include *participation* (focusing on the nature of participation by actors, participation effectiveness and interest group and/or gender-based representation), and *accountability* (manifest will of political actors and policy makers, the free provision of information by leaders, and the platforms for joint decision-making). Further indicators include *effectiveness* (effective production and transformation, transformation targets and outcomes), *efficiency* (resource allocation, resource inputs in transformation, transformation efficiency, viability of transformation process, and efficiency in waste use), and *equity* (clarity of benefits in production, clarity of benefits in transformation, equitable benefit-sharing, and trust in benefit-sharing process). Considering the crucial role conflicts play in shaping resource extraction in SSA, we modify the framework to capture *conflict management*.

Data collection

To commence the review, we first studied the PROFOR governance assessment framework to identify applicable indicators. The identified indicators and sub-indicators were helpful in the framing of the literature search themes. Relevant peer-reviewed articles were obtained following the systematic review approach (Moher et al. 2009; Petticrew and Robert 2006). Furthermore, and informed by some of the literature consulted, we modified the PROFOR framework to incorporate conflict management, considering its recurrence in the literature as a crucial governance issue in SSA. We arrived at seven main parameters (Table 1). This aided in the development of the search terms which we used to perform searches in key data bases such as Web of Science, Science Direct, Google Scholar, Scopus, and Springer. We first combined search themes of the main parameters (e.g., "accountability", "equity", "efficiency" "conflict management", "participation", and "effectiveness"), with key bioeconomy/nexus parameters (e.g., "water", "agriculture", "energy", "forest", "environmental resources" "natural resources", "transformation", "bioeconomy", "nexus approach", "optimal use", "efficiency". This was then further combined with "sub-Saharan Africa", "Central Africa", "East Africa", "North Africa", "Southern Africa", and "West Africa". Furthermore, the reviews enabled us to identify methods of data collection and analyses employed so far since the focus was on empirical articles (See Appendix). The review generated a total of 441 articles. Through de-duplication, we removed duplicates before proceeding to screen abstracts, methods, and key conclusions (Fig. 2). Inclusion was based on the following criteria: (i) The articles must be derived from one or more countries from SSA, (ii) They must be empirical in nature, (iii) The articles must capture any of the selected governance indicators, and (iv) The retained articles must additionally reflect the nexus approach in the context of bioeconomy. Through this screening and further systematic review (Moher et al. 2009), we arrived at 100 peer-reviewed empirical articles. One hundred and fifty-four cases studies were identified from the 100 retained articles (See Supplementary excel sheet).

Data analysis

Based on the analytical framework (Fig. 1), we reviewed the selected case studies focusing on parameters or proxies on accountability, equity, efficiency, conflict management, participation, and effectiveness. Microsoft Excel database was

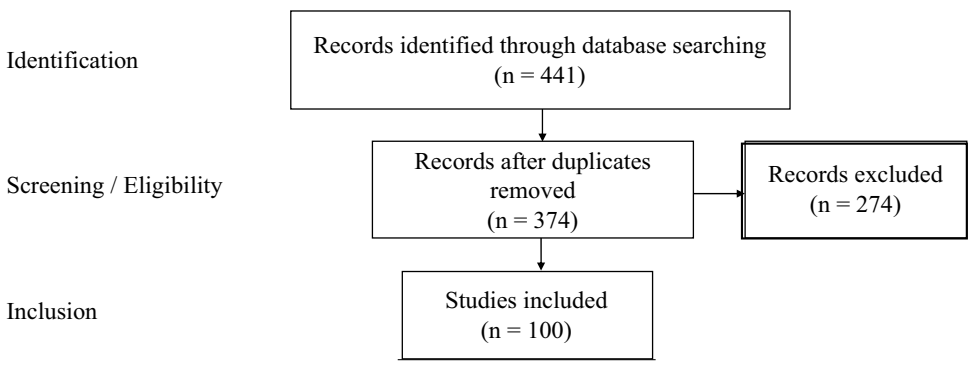

Fig. 2 Systematic review flow (after Moher et al. 2009)

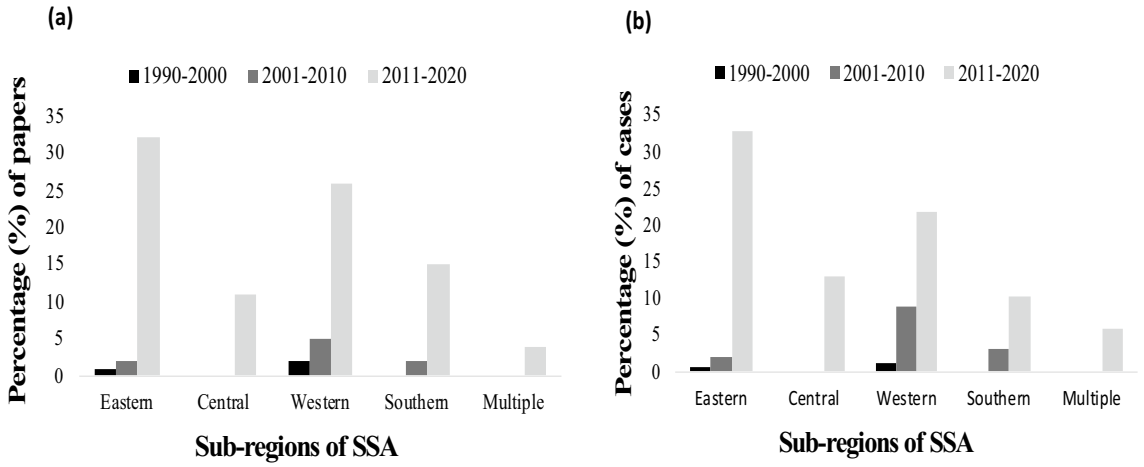

Fig. 3 Sub-regional distribution of papers and case studies on the nexus approach in environmental resource management in SSA

created in which the key themes and sub-themes of interest were synthesized. The excel sheet also presented the country case study and specific location, the sub-regional location, the key objectives, methods, and conclusions (Artmann and Sartison 2018). Furthermore, a synthesis of the methods employed in each article was presented in the spread sheet. This formed the data base from where descriptive statistics and narratives were developed to inform the results. A deductive approach was employed, in which the key and sub-indicators were identified through repeated reading of the articles to identify information which directly or indirectly expressed one or more of the indicators. Emerging content were clustered following the eight segments of analysis. Spatio-temporal variations in the articles and case studies were reported through descriptive statistics. Regression analyses, with the aid of the R software (version 4.0.1) (R Core Team 2020), were performed to determine how the influence of sub-regional variations and years of publication on the number of articles and case studies. The outcome of the multiple regression analyses also revealed variations with respect to the number of papers and case studies within the various sub-regions (eastern, central, western, and southern Africa), and the various years (1990–2000, 2001–2010, 2011–2020). The equations were formulated as follows:

$$\text{Number of papers (y)} = \alpha + \beta_1 * \text{sub} - \text{regions} + \beta_2 * \text{years} + \varepsilon \quad ------\text{Model 1},$$

$$\text{Number of cases studies (y)} = \alpha + \beta_1 * \text{sub} - \text{regions} + \beta_2 * \text{years} + \varepsilon \quad ------\text{Model 2}.$$

The components of the equations are defined as follows: number of papers and number of cases (y) = response variables, α = intercept, β = regression coefficient, sub-regions = first predictor or explanatory variable, years = last predictor or explanatory variable, ε = random error term.

Using the Quantum Global Information System (QGIS) software (version 3.12), we designed a map to show the countries from where the empirical cases were reviewed. This was reported in percentages. Furthermore, the indicators were discussed through thematic analysis and narratives. Further interpretation of the results and their implications were provided in a bid to guide the framing of forward-looking questions. Literature search and screening was done between October and November 2020, while the extraction of variables and subsequent analysis was done between December and February 2021.

Results

Review highlights on the nexus approach in environmental resource management

Sub-regional variations

The bulk (88%) of the peer-reviewed papers were published between 2011 and 2020. This is understandable, as interests on the nexus approach has only been recently (re) ignited, in SSA. East Africa recorded the highest percentage (Fig. 3a)—probably due to the rising interests by scholars from around the world, to engage in this part of SSA on the nexus subject. Also, the wood-based bioeconomy sector received significant attention in East Africa, considering the need to narrow the wood supply gap (Auch and Pretzsch 2020). Several papers drew from cases across more than one sub-region. With respect to the period 2001 and 2010, most of the studies originated from Western Africa. This is possibly explained by the rising interest to transit from

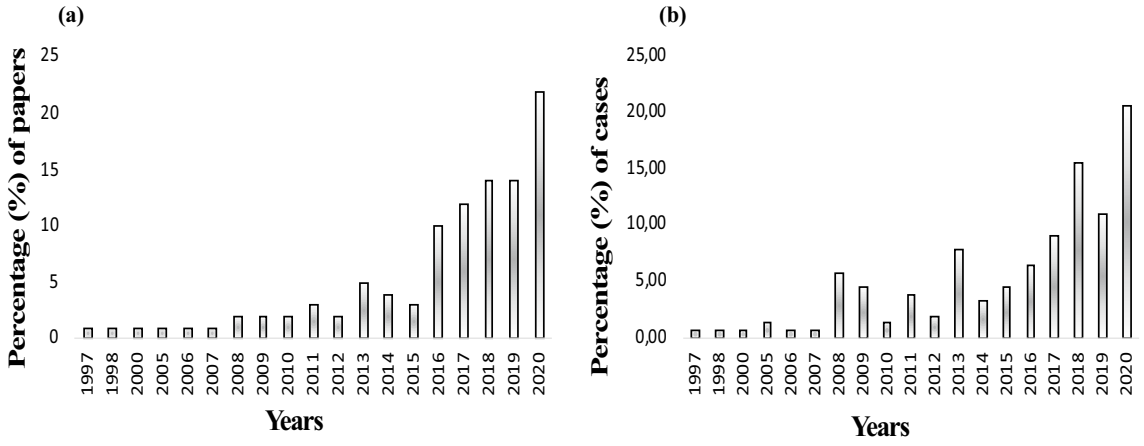

Fig. 4 The evolution of papers (**a**) and case studies (**b**) on the nexus approach in SSA

environmental resource extraction towards transformation by several countries in this sub-region. Surprisingly, no paper from the central African sub-region reported on the nexus approach in this period—perhaps due to the fact that researchers were more preoccupied with understanding governance mismatches in the extractive sector. The few papers recorded in the period 1990–2000 came from the Eastern part of SSA. For the case studies, 83% were recorded within 2011–2020, with Eastern Africa recording the highest number of cases, followed by Western Africa (Fig. 3b). About 6% of the reviewed case studies were conducted across two or more sub-regions of SSA, all of which were recorded within decade of 2011–2020 (Fig. 3b).

Table 1 presents the model coefficient estimates of the influence of sub-regions and years on the number of papers and case studies. Model 1 shows the relationship between (a) sub-regions (b) years and the number of papers that reported on environmental resource nexus in SSA. Model 2 predicts the relationship between (a) sub-regions (b) years and the number and the case studies that are associated with environmental resource nexus in SSA. Model 1 indicates that the predictor variables (sub-regions and years) statistically influence the number of papers that reported on environmental resource nexus in SSA. However, although there were some variations with respect to the number of papers that were reported from the various sub-regions (i.e., eastern, central, western, and southern Africa), these variations were not statistically significant. Model 2 reveals that the predictor variables (sub-regions and years) statistically influence the number of case studies on environmental resource nexus in SSA. Similar to the number of papers, the variations with respect to the number of case studies within the various sub-regions (eastern, central, western, and southern Africa), and the various years (1990–2000, 2001–2010, 2011–2020) were not statistically significant.

Evolution of the papers on the nexus approach in SSA

The 1990s recorded a relatively low percentage of studies, together with the early 2000s (Fig. 4a). Studies in this period reported marginal effectiveness in the transformation of products (Kersten et al. 1998; Okai and Boateng 2007) with relatively low efficiency (Kersten et al. 1998; Luoga et al. 2000). In addition, minimal stakeholder participation in the transformation process was reported from the empirical studies during this period. A steady increase, however, with respect to the percentage of studies was observed between 2008 and 2015 (Fig. 4a). This era coincided with growing international interests to achieve the Millennium Development Goals, and with mobilized interest towards the Copenhagen "Seal the Deal" climate conference. In the search for sustainable solutions, scholarly works were encouraged to address nexus-linked questions. Studies reported the effective transformation of natural resources (wood products, water, and land) (Maroyi 2014; Sseremba et al. 2011). However, very few papers (less than 10%) reported on efficient resource transformation (Descheemaeker et al. 2010; Ncube et al 2011). A sharp increase in the number of studies was observed in 2016 and this continues to increase sharply until the year 2020 (Fig. 4a). Arguably, this rise is also linked to rising international support for a bioeconomy transition (especially as part of the EU strategy), laying a solid foundation for the pursuit of research questions on this subject. There were mixed reports on the effectiveness and efficient transformation of natural resources during this period (Asamoah et al. 2020; Gmür 2020; Malisa et al. 2019; Samson et al. 2018; Reetsch et al. 2020). Just as the number of papers, very few case studies were conducted in the late 1990s. It was only until 2008 that a sharp increase in the case studies was observed, compared to the preceding years (Fig. 4b). The bulk of the case studies (22%) were

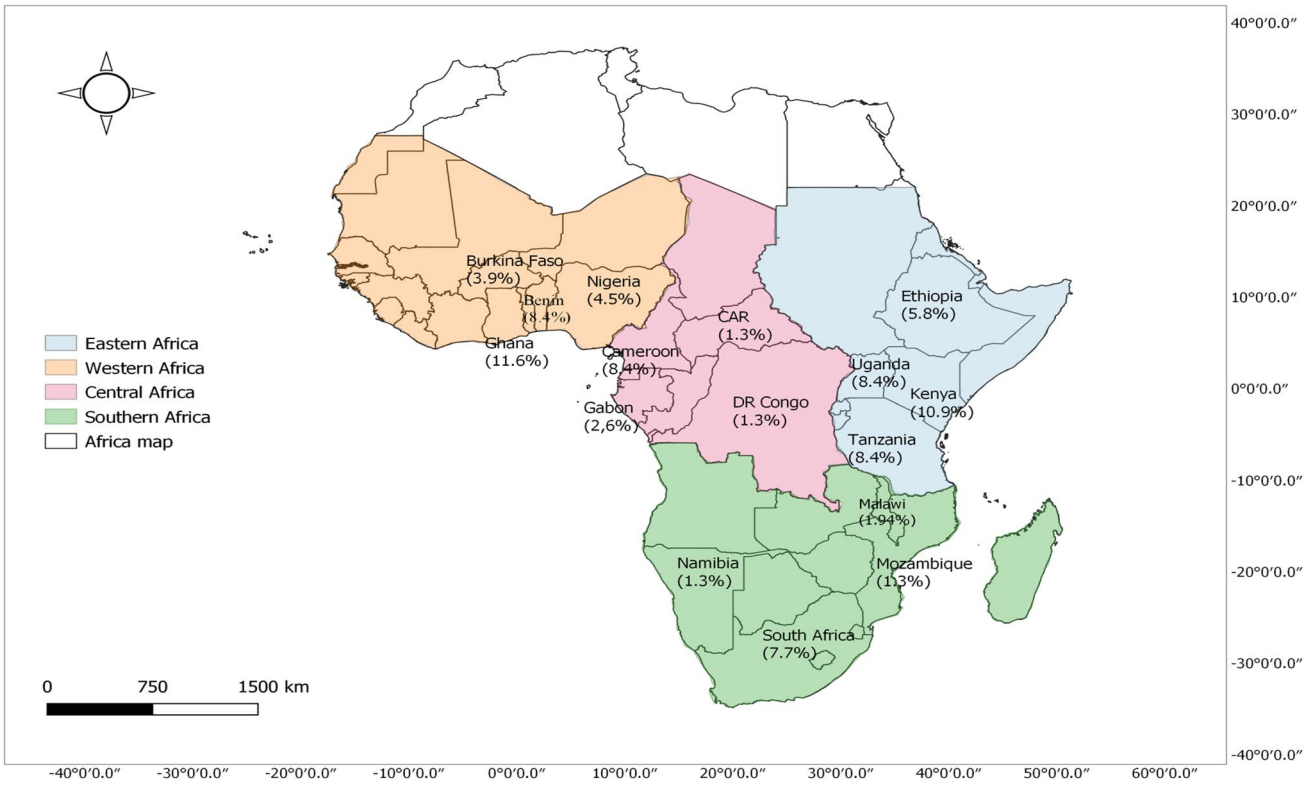

Fig. 5 Map of SSA showing reported country cases in the review

recorded in 2020, followed by 2018 (16%) and then 2019 (11%) (Fig. 4b). Cumulatively, this indicates rising interest for multi-country empirical evidence to shed light on environmental resource nexus questions in SSA.

Country-level characteristics

Country-level particularities

The study revealed an unequal distribution of case studies across SSA regions and countries. For instance, most of the studies in Eastern Africa came from Ethiopia, Kenya, Tanzania, and Uganda, with Kenya recording the highest percentage (almost 11% (Fig. 5). In Central Africa, most of the studies were conducted in Cameroon, Gabon, DR Congo, and Central African Republic (CAR), with Cameroon recording the highest percentage (almost 8.5%). This is surprising as a country like Equatorial Guinea hardly featured, despite increasing agro-based transformation in the country. Ghana, Benin, Nigeria, and Burkina Faso featured the most for Western Africa, with Ghana recording the highest: 11.6% (Fig. 5). With regards to the Southern African sub-region, Namibia, Malawi, Mozambique, and South Africa, recorded the highest number of studies, of which South Africa topped the list, with almost 8% of all the recorded studies. The disparity in number of studies per country and sub-region could also be explained by the fact that at certain periods, scholars from across the globe, seem to have prioritized particular sub-regions where they have interest and/or already established partnerships.

The distribution of governance parameters in SSA with a focus on effectiveness, efficiency, accountability andparticipation, and equity and conflict management is further presented in Fig. 6.

From the empirical works, only 5% explicitly mentioned nexus approach and bioeconomy. This further validates the dearth of empirical studies on the nexus approach as a whole, and the governance dimension in particular.

Key environmental resources linked to the nexus approach and bioeconomy in SSA

Table 2 presents the key environmental resources that are linked to the nexus approach. Forest resources, water, and land are the natural resources, which are associated with environmental resource management in SSA. Transformative and productive indicators on forest resources and/or land were more prominent in the literature from Eastern and Western Africa. However, water was prominent in Southern and Eastern Africa.

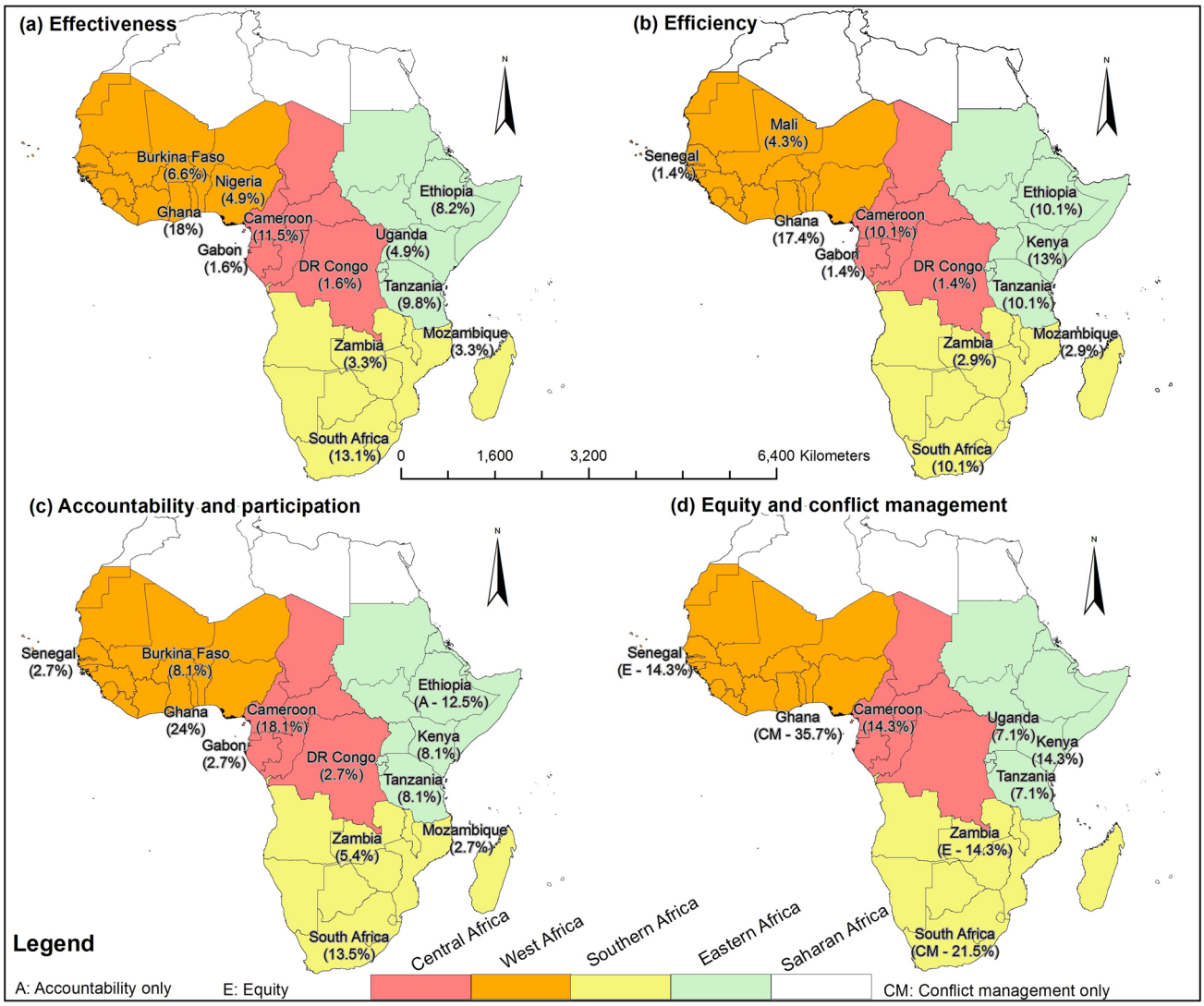

Fig. 6 distribution of governance parameters in SSA [(**a**) = effectiveness; (**b**) = efficiency; (**c**) = accountability and participation; and (**d**) = equity and conflict management]

Table 2 Frequency of the key environmental resources linked to the nexus approach

Sub-regions	Resources							
	Forest/forest resources		Water		Land		Multiple (land, water)	
	Cases	Papers	Cases	Papers	Cases	Papers	Cases	Papers
Eastern	18	14	16	8	19	12	1	1
Central	15	8	0	0	5	3	0	0
Western	34	18	2	2	12	11	2	2
Southern	14	10	6	6	1	1	0	0
Multiple	5	2	0	0	4	2	0	0
Total	86	52	24	16	41	29	3	3

Table 3 Sub-regional distribution of the governance parameters

Governance parameters	Sub-regions of SSA					
	Eastern (%)	Central (%)	Western (%)	Southern (%)	Multiple (%)	Total (%)
Efficiency	29	9	19	10	2	69
Effectiveness	16	9	22	11	3	61
Participation	11	5	13	7	1	37
Accountability	13	4	4	3	0	24
Conflict/conflict management	4	2	5	3	0	14
Equity	4	1	1	0	1	7

Table 4 Methodology employed for the case studies on the nexus approach and environmental resource governance in SSA

Methodology	Sub-regions of SSA					
	Eastern (%)	Central (%)	Western (%)	Southern (%)	Multiple (%)	Total (%)
Quantitative	13	5	9	10	2	39
Qualitative	11	1	8	3	1	24
Mixed method	11	5	16	4	1	37

The governance parameters

Overview of the governance parameters

Six governance indicators were analyzed in this study. Only two of the indicators (efficiency and effectiveness) were captured in more than 50% of the literature (Table 3). The other four (i.e., accountability, equity, participation, and conflict management) were recorded in less than 40% of the papers (Table 4), 10 percentage points lower than efficiency and effectiveness. This implies that issues related to (a) accountability in the transformation or production process, (b) equitable sharing of benefits, clarity of rules, clarity of sanctions; (c) stakeholder participation and/or gender/interest group representation; and (d) conflict resolution platforms, are still to gain grounds in nexus thinking in SSA. With respect to effectiveness and efficiency, a bulk of the studies emanate from Eastern and Western Africa (Table 3), indicating that Southern and Central Africa still lack scientific evidence to explain these indicators.

Accountability

Accountability, mirrored through three parameters: political will, information flow and joint decision-making, registered 24%in the reviewed papers. Regarding political will, studies in east Africa reveal the existence of the lack of political will in enhancing the transformation of charcoal waste in Ethiopia, and for land resource utilization in Kenya (Auch and Pretzsch 2020). Some advances have been made on this subject in Southern Africa. Studies in Namibia, for instance, explained the demonstration of good political will by introducing benefit-sharing mechanisms to facilitate bioeconomy practice—the newly introduced access and benefit-sharing law (Heeren-Hauser et al. 2020). Closely linked to political will is the reporting on information flow. This was characterized by the recurrence of information asymmetry in Central Africa. For instance, studies report that up to 40% of forest-linked actors were not aware of the policy framework in forestry (Awono et al. 2016). Besides information flow, the literature in West Africa (Ghana) points to the lack of transparency in the acquisition of incentives and innovative technologies to improve the bamboo-based resource nexus. This largely affects large scale developers (Addo-Danso et al. 2019). Information flow deficits were also reported in East Africa – indicating that it stalls innovations to spur transitions to the processing and upgrading of bio-resources (Auch and Pretzsch 2020). Besides growing inefficiency in timber transformation, information flow deficits reportedly stalled the transformation of forest-based products in Uganda (Sseremba et al. 2011), while its availability improved technical efficiency in Ghana (Wongnaa and Awunyo-Vitor 2018). As an accountability indicator, joint decision-making was recurrent in the literature from East Africa. While this was lacking in Kenya's water resource sector (Kanyua 2020), it was reported to be positive for Ethiopia as it enhanced honey transformation and its linked products (value chains), while ushering multiplier effects (Meaton et al. 2020). Articles in Central Africa reported that the growth of the artisanal chain saw milling (CSM) was partly facilitated by the recognition and upholding of traditional governance institutions (Lescuyer et al. 2013). This promoted joint decision-making but did not assure efficiency in transformation and equity in the benefit distribution. Gaps in joint decision-making

were reported for Senegal's charcoal sector (Faye and Ribot 2017), which hamper progress towards efficient resource transformation and value upgrading.

Effectiveness

Sixty-one percent of the papers highlighted effectiveness indicators in environmental resource nexus. In Central Africa (Cameroon), for instance, secondary processing was implemented to effectively transform poles into products, by crafting, burning, carving, cutting, fabrication, lacquering and, in the most complex process, into paper (Ingram and Tieguhong 2013). Besides bamboo, wood-processing activities were reportedly undertaken since 2003 when a timber sawmills operation was instituted in South-West Cameroon (Tafon and Saunders 2015). This is similar to the processing of wood at sawmills in Tanzania (Kalonga et al. 2014). However, whether wood waste is processed into other usable forms as bioeconomy demands were unanswered by these papers. Studies also reported the transformation of neem plant (*Azadirachta indica*) to neem oil and also shea butter from (*Vitellaria paradoxa*) in Cameroon and the DRC (Tieguhong et al. 2012). In East Africa (Ethiopia), Lowore et al. (2018) reported effective product transformation, characterized by the semi-processing or primary processing of NTFPs into honey, including pyrolysis, the process used to produce charcoal from wood (Nabukalu and Gieré 2019). Farm waste in Tanzania is converted into bio-fertilizer (Reetsch et al. 2020). In Malawi (Southern Africa), baobab fruits were reportedly processed into a variety of food and non-food products, such as fruit juice, ice-lollies, sweets, and cosmetics (Darr et al. 2020), while there is semi-processing of honey in Zambia (Lowore et al. 2020). Muchara et al (2016) reported the transformation of wastewater, while water is effectively produced to help in the irrigation of farm crops in South Africa (Malisa et al. 2019). In reporting about forest-based bioeconomy in Madagascar, Neimark and Healy (2018) showed the production system chain from growing and wild collection of castor for the bio-oil firm, as well as exporting it for European buyers who purchase the pressed oil in bulk. However, only 44% of all wood harvest by the company was used for products in Mozambique (Nanvonamuquitxo et al. 2017).

In Burkina Faso, shea value chain activities range from shea nut processing to marketing of the butter and its by-products (soaps and other cosmetics) (Noumi et al. 2013). Ineffective and inefficient transformation is common in several papers consulted, including Ghana, where it is estimated that for every tree felled, nearly 50% of the tree volume is left in the forest in the form of branches, crownwood, and stumps (Okai and Boateng 2007). This also applies to honey production, where the honey value chain was reportedly not in full operation, with 90% of the respondents selling honey in bottles without labeling (Ahenkan and Boon 2010). In terms of wood transformation, 79 primary wood-processing facilities were reportedly found in Cameroon. Of this number, 57% are foreign-owned, 35% by local investors and 8% by joint ventures. In the industry, sawmills represent about 82% of the total number of factories, while the number of veneer and plywood factories account for 11% and 7%, respectively. Wood residues generated in the rainforest and wood-processing residues were reportedly inefficiently utilized (Nzotcha and Kenfack 2019). Yobo et al. (2020) also reported the processing of bush mango into jam and juice products, sauce making and additives. In Uganda, Sseremba et al. (2011) reported the use of wood to produce furniture. The commonest type of wood waste was planer shavings, which were not utilized effectively. In Benin, Enhabor et al. (2015) showed that slabs made up the highest percentage of wood waste with mean value of 21% while sawdust, wanes and bark accounted for 10%, 9% and 6%, respectively. This brought the percentage of wood waste during sawmilling operations in Benin City to 47%. Estimation of the exact volume of wastes resulting from sawmilling operations will motivate future bio-economic studies to capitalize on efficiency. The land–water nexus was equally highlighted through the transformation of rain-fed agriculture for irrigation (Anang et al. 2017).

Efficiency

Of all the governance indicators, efficiency was the most recurrent in the reviewed papers, accounting for 69%. In Cameroon, for instance, bamboo was reportedly used efficiently since even their leaves provide pollen for bees and forage for animals including elephants (Ingram and Tieguhong 2013). Variables such as farm size, experience and land-use intensity significantly enhanced the efficiency of cassava producers. Waste wood was used for charcoal production (Tafon and Saunders 2015). In East Africa, Lowore et al. (2018) revealed efficiency in honey production, as forest beekeeping is sustainable and does not undermine the reproductive capacity of the bees, or the plants on which they feed. In Uganda, little to no innovation exists to manage waste materials such as ash and polluting gases along the supply chain (Nabukalu and Gieré 2019). Samson et al. (2018) showed how wastewater from fish ponds is used efficiently by farmers as irrigation water for vegetable production. In Southern Africa (Zambia), wax from the honeycomb was inefficiently utilized (Lowore 2020). Transformation efficiency is compromised, as reported in Kenya (Kiruki et al. 2019); and charcoal wastes are not further utilized. In East African agriculture, Wassihun et al. (2019) reported that crop production (potato) showed a technical efficiency deficit of 54%. Hence, if inputs are used to their maximum potential, there will be considerable gain from improvement

in technical efficiency. In the land–water nexus, Anang et al. (2017) reported that the irrigation technology was more efficient—on average, as irrigators were nine percentage points more efficient than non-irrigators.

The use of agro-forestry waste materials to produce activated carbon was reported in Malawi and Zimbabwe (Ncube et al. 2011; Lisboa et al. 2020). This also includes the recycling of wastewater in South Africa (Malisa et al. 2019), although it was inefficiently utilized due to poor management (Muchara et al. 2016). However, in Mozambique, Nanvonamuquitxo et al. (2017) noted that only 44% of all wood harvest by the company was transformed, and another 56% remained in the forest as wood waste. In West Africa, 80% of the timber production companies do not manage the waste (Asamoah et al. 2020). Conversely, in Benin, studies reported that all parts of baobab plants are used as raw materials (De Caluwe et al. 2009). The average oil extraction efficiency from the seeds was reported to be 23% and varied among sites. In Ghana, Boon and Anuga (2020) opined that controlling natural resources, closing loops in Ghana's agricultural sector will result in high efficiency in the exploitation of natural resources. Kansiime et al. (2018) held that farm-specialized households exhibited technical inefficiency in the use of labor and fertilizer compared to other farm types.

Equity

Equity indicators only accounted for 7% of the total review. This sparing percentage denotes the limited growth in the literature on resource nexus approach which addresses issues of equity. Yet, it should be noted that issues of equity actually breed conflict. In Central Africa (Cameroon), Tafon and Saunders (2015) reported that there was lack of clarity of benefits in forest resource transformation, as companies failed to provide the socio-economic benefits promised. In water use and transformation in Kenya, the non-clarity of user drawing rights, and the overlooking of monitoring and sanctioning inefficient water resource use were reported (Kanyua 2020). However, forest resource actors from certified forest communities were found to earn higher incomes than those from non- FSC forests in Tanzania (Kalonga 2014). Such equitable access and property rights were also applicable to land (Gmür 2020). West African (Senegal's) forest resource use sector demonstrated clarity of rules (Faye and Ribot 2017).

Participation

Indicators of participation were reported in 37% of the reviews, covering all four sub-regions. In Central Africa, participation in bamboo transformation was minimal, as only chiefs participated by helping to regulate the retail market of the product (Ingram and Tiehugang 2013). This was also evident in wood processing, as elite capture prevailed in the decision to allocate the land for wood processing (Tafon and Saunders 2015). In East Africa, Nabukalu and Gieré (2019) reported that local people participate in the production and transformation of wood into charcoal in Uganda. The adoption of a more inclusive approach in Tanzania made it possible for the poor to be allowed to participate in the efficient use of water without any serious restrictions by authorities (Samson et al. 2018). Resource use efficiency in maize production was facilitated through the inclusion of smallholder farmers to actively participate (Salat and Swallow 2018), while an unfair representation of female actors in charcoal production was reported in Kenya (Kiruki et al. 2019). Participation in the transformation of NTFPs was registered in Zambia (southern Africa), as beekeepers participated fully in extracting the honeycomb and in the semi-processing of the honey (Lowore 2020). In explaining participation in the water-food-energy nexus, Sinyolo et al. (2014) reported the participation of about 1,500 irrigators in the irrigation scheme, growing various crops. The study highlights the relevance of strengthening farmers' organizational capacity and local institutions for enhancing the water security status of farmers in smallholder irrigation schemes. In West Africa, Tomaselli et al. (2013) showed how 72 community-based enterprises were incubated in 26 villages, and 11 products were effectively marketed in Gambia. Furthermore, the nexus is still far from being achieved at the institutional level, as the overlap of competencies prevails (Nchanji and Bellwood-Howard 2018). Jasaw et al. (2017) reported the dominance of females (t≈ 90%) in Shea kernel production—shea butter production is women dominated with little participation by men. This is similar to NTFPs transformation in Central Africa (Gabon), where Yobo et al. (2020) reported that female-headed households dominate harvesting (21.8%), processing/trading (10.3%) and the trading stages (55.2%), compared to males. By implication, female processors and traders earn 5 times more income than their male counterparts.

Conflicts and conflict management

The review indicated that conflicts and conflict management indicators occupied 14% of the total articles. Despite growing evidence of conflicts at the extractive phase of environmental resources in SSA, this indicator is yet to be sufficiently covered in empirical works on the nexus approach. Tafon and Saunders (2015) reported growing conflicts in Central Africa, between timber processing companies and communities, over the failure to manage waste wood as promised. However, such conflicts in the water sector were hardly identified and managed in East Africa (Kanyua

2020). This could be partly due to the lack of an efficient conflict resolution mechanism as reported by Salman et al. (2020). Closely linked to these resources is land in Tanzania. Despite the rolling out of cooperate social responsibility and compensatory schemes by land grabbers, villagers resisted the process of transforming their area into forest plantations (Gmür 2020). In some cases, this has been managed through litigation, as in Kenya (Archambault 2016). Environmental resource use transformation towards ecotourism in Southern Africa was associated with perceived exclusion of community members and a lack of transparency (Musavengane 2019). Furthermore, in analyzing the water–food–energy nexus, Sinyolo et al. (2014) reported the occurrence of conflicts as a contributor to the decrease in household water security. Regarding NTFP transformation, Jasaw et al. (2017) explained that conflicts implications are evident due to the nature of input requirement and production process as more processing takes place and sustainability is not assured.

Methodology applied in reviewed case studies

Table 4 presents the methodologies that were employed for the case studies used in this review. The bulk of the studies (39%) employed quantitative research approaches; followed by mixed-method approaches (37%). The remaining 24% employed qualitative methods. With respect to quantitative case studies, East Africa recorded the highest number, followed by Southern Africa. Very minimal papers reported on quantitative case studies from more than one sub-region. With respect to qualitative studies, Eastern Africa recorded the greatest proportion, followed by Western Africa. Considering the complex nature of the nexus approach, it is imperative to use more complementary evidence to offer a comprehensive understanding of this approach to resource governance. This might be feasible by employing other qualitative studies such as key informant interviews (KIIs), shadowing, etc. However, this could only be ascertained after an in-depth methods-based review is conducted. A very small proportion of the studies (1%) that spanned across more than one sub-region employed a mixture of both qualitative and quantitative research approaches. On the whole, 63% of the studies have either made use of qualitative or quantitative approaches, separately, indicating the need for more complementary studies that apply mixed methods approaches.

Discussion

With recent efforts towards enhancing the nexus approach in natural resource use and management, SSA presents a useful landscape to explore governance processes that shape the nexus approach, amidst the current knowledge fragmentation. This paper (i) explores the extent to which governance indicators been captured in empirical studies on the *nexus approach* in SSA, and (ii) discusses questions and approaches that should inform its future research in SSA. On the whole, the paper reports the existence of sub-regional variations in the application of nexus thinking, with emphasis on first-level resource transformation. Furthermore, very few studies (5%) explicitly mentioned the nexus approach and bioeconomy, suggesting a dearth in scientific knowledge on the subject (Tafon and Saunders 2015; Kiruki et al. 2019; Lowore 2020). The increasing reliance on quasi-transformed or non-transformed natural resources to sustain the economy of SSA signals a weak transition propensity to more stable economies. In the meantime, several sustainable development goals rely on the extension of resource use linkages to reap multiple economic benefits. This is yet to be sufficiently observed for SSA. The sub-Continent's persistent reliance on first-level resource transformation stalls resource use efficiency (nexus practice) and partly explains the wavy economic situation of most of its countries (Olusi and Olagunju 2005; Moseley 2014). Besides limited nexus practice, other factors such as the differential extent of government intervention, globalization, access to finance, among others further explain the increasing reliance on primary production (Kim and Lin 2017). Technological improvements have instead prioritized the extractive and non-transformative sectors (Doytch and Mendoza 2015), with scholars recommending that SSA should concentrate on the sector in which it possesses relative advantage over international actors—primary production (Naude et al. 2010).

Effectiveness and efficiency questions are seemingly gaining traction, with more than 50% observed in the nexus literature in SSA. While over 60% of the studies mentioned effectiveness indicators in environmental resource nexus, emphasis was on sector-specific resource use and processing. The recurrent resource in this case is wood-based and bamboo resources which are transformed through crafting, burning, carving, cutting, fabrication. This was recurrent in Central Africa (Cameroon & DRC) (Ingram and Tieguhong 2013; Tafon and Saunders 2015)—probably due to its forest rich Congo Basin which is a hot spot for timber and NTFPs harvesting. Conditions under which more effective applications of the nexus approach could be instituted need to be carefully considered in scientific and policy circles. Efficiency was the most recurrent in the literature (69%). In parts of East Africa, processes to optimize natural resource-based benefits have been engaged through participative innovation platforms (PIPs) (Auch and Pretzsch 2020). Yet, studies that show its promotion in the natural resource nexus are few (Tafon and Saunders 2015; Kiruki et al. 2019; Lowore 2020). For instance, close to 56% of harvested wood end up wasted in the forests (Nanvonamuquitxo et al. 2017). To corroborate this, Shannak et al. (2018) argue

that most of the existing models on the resource nexus (especially, water–energy–food) do not capture the interactions among nexus components; this is related to the paucity of data. This further substantiates the claim that in practice, natural resource use inefficiency prevails in several parts of SSA. Technology seems to be gaining grounds in promoting resource use efficiency as prominent in Southern Africa (Baninla et al. 2020). On the contrary, previous studies report that in the past few decades, East Africa showed the least resource efficiency, while Western and Central Africa had the highest cumulative material consumption of 54 Gt (Baninla et al. 2020). This supports the views of Shannak et al. (2018) who explained how despite the significant energy requirements of the agricultural sector, few scholars and practitioners have combined water and energy requirements in the nexus paradigm. At micro-level, situations linked to geographical attributes tend to introduce or enhance complexity in the understanding of the nexus approach. These must be fully uncovered to assure congruence between resource efficient transformation interventions/equipment and the status of the resource.

Participation as a parameter has still not received significant attention. Concepts of participation gained grounds in the early 1990 with growing calls to promote decentralized natural resource management. However, how participation is conceptualized and applied in the nexus approach remains relatively less understood (Urbinatti et al. 2020). Although participation is reported in 37% of the reviews, covering all four sub-regions, this was hardly captured in environmental resource systems, which demonstrate application of the nexus approach. Increased participation promoted resource use efficiency in some sectors (Salat and Swallow 2018), while in others, it led to an unfair representation of female actors in single resource use arrangements (Kiruki et al. 2019). Participation is closely linked to accountability. Despite increasing calls to promote good political will, assure joint decision-making and information flow, scientific evidences are still scant, as only about 24% reported at least one of the accountability proxies. This emanated largely from East Africa—Ethiopia and Kenya (Auch and Pretzsch 2020), Southern Africa (Namibia). Besides this, information asymmetry was predominant in Central Africa (Awono et al. 2016; Kimengsi and Bhusal 2021), while the lack of transparency in West Africa (Ghana and Senegal) was reported (Addo-Danso et al. 2019).

Surprisingly, only 7% of the studies captured equity indicators. The valorization of the nexus approach requires a careful rethink of the multi-sectoral actors, their interests, beliefs, and benefits. This could pave the way to better appreciate equity issues which have been studied in isolated resource systems. While some sectors demonstrated clarity of rules—e.g., Senegal's forest resource use sector (Faye and Ribot 2017), such isolated cases show that conditions to mainstream equity in nexus thinking need to be fully explored. Yet, issues of equity actually breed conflict. Despite growing evidence of conflicts at the extractive phase of environmental resources in SSA, only about 14% of studies touched on conflicts and conflict management questions. Only in the analysis of the water–food–energy nexus, with Sinyolo et al. (2014) reporting that factors such as the occurrence of conflicts and location at the tail-end of the canal were found to decrease household water security.

Review limitations

This review provides a snapshot of what exists in the literature on the nexus approach in the context of bioeconomy transitioning in SSA. Using the six PROFOR governance parameters might be insufficient as further details relating to region-specific and/or country-specific information is required. For instance, participation or conflict management is complex and requires a better understanding—of the level of participation (Balgah 2019; Musavengane 2019). It is impossible to elaborate all these details in a single review. Further detailed reviews and empirical analysis focusing on a few governance parameters (e.g., conflict management) could be conducted to shed more light on the subject. The review articles considered were those published in English language, and which are indexed in certain databases. Papers from local or regional journals could have evidently edified this review. However, we did not consult such articles. What is however clear is that, with very few journal articles comprehensively dealing with the subject, there is an opportunity—a fresh research area which should be explored by scholars. Methodologically, a profound analysis of the approaches used in the study was not covered here. This paper only reports on whether the studies used qualitative, or quantitative approaches, or both. Details of how each of these approaches were implemented is required. A short methods-based review (Palmatier et al. 2018) could address this, focusing on the synthesis of the research design and instruments, the data collection and analysis process (including their strengths and weaknesses), and the proposition of other approaches that could complement earlier studies.

Conclusion

More than 60% of the papers captured effectiveness in the implementation of environmental resource use. From the foregoing, the following conclusions are plausible: First, nexus thinking is still to gain significant traction in SSA; sub-regional variations exist in its application, as gleaned from the few studies that explicitly captured it. This predicament led to the increasing reliance on quasi-transformed or

non-transformed natural resources to sustain the economy of SSA. The upscaling of nexus-linked technology—prioritizing several interlinked resource use streams—demands scientific and policy urgency. Second, at least half of the empirical works captured effectiveness and efficiency, while close to 40% reported participation, albeit on sector-specific resource use and processing. Third, while participation indicators were reported in all four sub-regions, the degree of participation at local level remains unclear. Fourth, despite the fact that efficiency is the most recurrent in the literature (69%), its assurance in resource nexus and transformation was scarce. Fifth, lack of political will and information asymmetry stalls accountability. Furthermore, equity as a governance indicator hardly applies as less than 10% of the papers captured it. The valorization of the nexus approach requires a careful rethink of the multi-sectoral actors, their interests, beliefs, and benefits. This could pave the way for a better appreciation of equity issues which have been studied in isolated resource systems. Sixth, with less than 15% of the studies capturing conflict management, there is need for a proper diagnosis of conflicts and conflict management approaches in the resource nexus. To conclude, mixed-method approaches in governance questions should be prioritized.

Appendix

Search combinations employed in the review.

Governance Parameters	Sub-governance parameters	Search combinations
Accountability	Political will Information flow Joint decision-making Transparency	"Environmental resources" **or** "Natural resources" **or** Forest or Land **or** water and transformation **or** "optimal use" **or** efficiency **or** waste and "political will" **or** information flow **or** joint decision-making **or** transparency and Sub-Sahara Africa **or** "east Africa" **or** "West Africa" **or** "central Africa" **or** "southern Africa"
Effectiveness	Product transformation, Effective production, Effective utilization, Resource transformation	"Environmental resources" **or** "Natural resources" **or** Forest **or** Land **or** water and transformation **or** "optimal use" **or** efficiency **or** waste **and** Product transformation **or** effective production **or** effective utilization **or** resource transformation **and** Sub-Sahara Africa **or** "east Africa" **or** "West Africa" **or** "central Africa" **or** "southern Africa"
Efficiency	Viability of transformation process, Resource allocation, Resource inputs and transformation, Transformation efficiency	"Environmental resources" **or** "Natural resources" **or** Forest **or** Land or water **and** transformation **or** "optimal use" **or** efficiency **or** waste **and** Viability of transformation process **or** resource allocation **or** resource inputs **and** transformation **or** transformation efficiency **and** Sub-Sahara Africa **or** "east Africa" **or** "West Africa" **or** "central Africa" **or** "southern Africa"
Equity	Clarity of benefits, Clarity of rules, Equitable benefits sharing	"Environmental resource" **or** "Natural resource" **or** Forest **or** Land **or** water **and** transformation **or** "optimal use" **or** efficiency **or** waste **and** clarity of benefits or clarity of rules **or** equitable benefit-sharing **and** Sub-Sahara Africa **or** "east Africa" **or** "West Africa" **or** "central Africa" **or** "southern Africa"

Governance Parameters	Sub-governance parameters	Search combinations
Participation	Stakeholder participation Elite domination, Gender/interest group representation	"Environmental resources" **or** "Natural resources" **or** Forest **or** Land **or** water **and** transformation **or** "optimal use" **or** efficiency **or** waste **and** participation **or** elite dominance **or** gender representation **and** Sub-Sahara Africa **or** "east Africa" **or** "West Africa" **or** "central Africa" **or** "southern Africa"
Conflict Management	Resource use conflict, Actor/interest conflict, Conflict resolution	"Environmental resources" **or** "Natural resources" **or** Forest **or** Land **or** water and transformation **or** "optimal use" **or** efficiency or waste **and** conflict **or** conflict mechanism **or** conflict resolution **and** Sub-Sahara Africa **or** "east Africa" **or** "West Africa" **or** "central Africa" **or** "southern Africa"

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