Article:
Barrahmoune, A. and Matanle, P. (2026) Unequal geographies and socio-demographic challenges in resource nexus research: a systematic review. Sustainability Nexus Forum, 34 (1). 7. ISSN: 2948-1619

https://doi.org/10.1007/s00550-026-00589-1

Sustainability Nexus Forum (2026) 34:7
https://doi.org/10.1007/s00550-026-00589-1

ORIGINAL PAPER

Unequal geographies and socio-demographic challenges in resource nexus research: a systematic review

Anass Barrahmoune[1,2] · **Peter Matanle**[1]

Received: 7 June 2025 / Revised: 11 March 2026 / Accepted: 13 March 2026

Abstract
The Resource Nexus has gained prominence as a conceptual framework for understanding and managing interdependencies among natural resources amid escalating global environmental and societal pressures. However, despite its growing adoption, existing scholarship has predominantly emphasised methodological and conceptual innovation, often at the expense of critical geographic and socio-demographic dimensions that shape resource governance and mediate nexus interactions. This systematic review addresses this gap by synthesising empirical insights from 84 peer-reviewed studies identified through a structured search and screening process, and focusing on interrelations and trade-offs among land, food, water, and energy systems. We critically examine the extent to which geographic and socio-demographic variables have been integrated into nexus research since the framework's popularisation at the 2011 Bonn Nexus Conference. Our findings reveal notable thematic and geographic imbalances, with concentrated attention on population growth and economic development in East and South Asia, while issues such as migration, population decline, and resource-related conflicts, as well as underrepresented regions including Central Asia, West Asia, and Oceania, remain significant blind spots. We argue that these gaps constrain the nexus framework's potential to inform inclusive and context-sensitive governance, and we advocate for a shift in nexus research towards more empirically grounded and inclusive approaches that explicitly address geographic diversity and socio-demographic complexity. In doing so, we contend that such an approach can enhance the analytical utility of the Resource Nexus framework and provide guidance for scholars, policymakers, and practitioners seeking to develop integrated, context-aware strategies aligned with the Sustainable Development Goals.

Keywords Resource nexus · Socio-demographic challenges · Geographic disparities · Nexus governance · Sustainability · Systematic review

1 Introduction

Global challenges such as climate change, socioeconomic development, demographic shifts, and escalating natural resource scarcity emphasise the urgency of understanding and governing the complex interactions between society and natural resources in pursuit of sustainable development. In response to this imperative, the concept of "Resource Nexus" emerged as a guiding paradigm for researchers, policymakers, and practitioners seeking integrated approaches to increasingly interdependent resource demands and their associated trade-offs (Daher and Mohtar 2018; Bleischwitz et al. 2018; Morales-García and Rubio 2023).

The concept of "Resource Nexus" has long been discussed in integrative resource governance scholarship as a way to conceptualise interrelations and trade-offs among core natural resource systems (most notably land, food, water, and energy resources), and it has become more prominently featured in public policy and research programs over the past decade. Following its consolidation at the Bonn 2011 Nexus Conferences (Hoff 2011), the nexus paradigm has gained considerable traction, prompting a proliferation of research that frames resource interdependencies across diverse scales, disciplines, and methodological approaches

✉ Anass Barrahmoune
anass.barrahmoune@gmail.com

Peter Matanle
peter.matanle@cantab.net

[1] School of East Asian Studies, University of Sheffield, Sheffield S10 2TN, UK

[2] Graduate School of Humanities and Social Sciences, Okayama University, Okayama, Japan

Published online: 24 March 2026

(Opejin et al. 2020; Molefe and Inglesi-Lotz 2022; Estoque 2023). However, as the concept matures, concerns have emerged that rapid policy uptake may encourage a trajectory of normative abstraction and rhetorical inflation akin to that observed for the concept of sustainability (Albrecht et al. 2018; Hejnowicz et al. 2022). Such a trajectory risks weakening the nexus framework's ability to capture and engage with the context-specific socio-demographic and geographic conditions that structure resource dynamics and governance.

While existing nexus scholarship has made substantial contributions to conceptual development and methodological innovation, contextual dimensions have often remained peripheral in empirical case-study synthesis. A growing body of reviews reflects this tendency. Numerous reviews have focused on theorising, critiquing, and tracing the conceptual evolution of the nexus paradigm (Endo et al. 2017; Zhang et al. 2018; Liu et al. 2018; Ghodsvali et al. 2019; Urbinatti et al. 2020; van Zanten et al. 2020; Molajou et al. 2021; Purwanto et al. 2021a; Brouwer et al. 2024; Estoque 2023). Others have prioritised methodological advancements, documenting the development of assessment tools and modelling approaches (Khaddoura and El Khatib 2017; Dai et al. 2018; Albrecht et al. 2018; Mannan et al. 2018; Namany et al. 2019; Endo et al. 2020; Fayiha et al. 2020; Soleimanian et al. 2022; Borge-Diez et al. 2022). A further subset has explored practical applications, particularly in urban settings (Zhang et al. 2019a, b; Arthur et al. 2019; Newell et al. 2019; Meng et al. 2019).

Yet, a comprehensive review that systematically examines how geographic and socio-demographic conditions shape nexus interactions and governance across contexts remains lacking. This review addresses that gap by foregrounding the geo-socio-demographic realities through which resource nexus dynamics are produced, mediated, and governed in a rapidly changing world (Giampietro 2018). More specifically, it considers how socioeconomic and demographic processes, as they unfold within particular geographic and geospatial settings, configure nexus trade-offs, vulnerabilities, and governance challenges.

Building on this perspective, this systematic review critically assesses how such socio-demographic and geographic variations have been addressed in nexus research, with particular attention to the Land-Food-Water-Energy nexus across scales and regions. It specifically aims to evaluate the extent and nature of engagement with these factors, identify where nexus research has primarily focused and where it has not fully illuminated their significance, and derive implications for advancing operationally relevant nexus governance. To address these aims, we draw on a comprehensive, systematically selected sample of articles and book chapters published since the 2011 Bonn Conference to evaluate the extent and nature of engagement with these factors. We place particular emphasis on how these realities are addressed while also identifying areas where nexus research has primarily focused, and where it has not fully illuminated their significance. Eventually, we build on these insights to discuss and chart a course towards transitioning from a conceptual to an operational nexus of actions, addressing how this could inform the practical pursuit of sustainability.

2 Methodology

In designing this systematic literature review, we adopted a stepwise approach to locate, select, and analyse the nexus scholarship, focusing primarily on how geographic and socio-demographic dimensions are addressed in case study research (Fig. 1). The review followed PRISMA guidelines (Tricco et al. 2018; Page et al. 2021) and comprised four consecutive stages: (1) database selection, (2) search-term development, (3) screening, and (4) synthesis and analysis.

2.1 Database selection

As an initial scoping step, we examined 27 nexus-focused review articles to identify which bibliographic databases are most commonly used in nexus scholarship and therefore most suitable for the present systematic review. These reviews were identified through a preliminary search using broad nexus-related keywords (e.g., water-energy-food nexus, resource nexus, resource systems, sustainability nexus) across multiple sources and were purposively selected to ensure thematic and disciplinary coverage across the 2011–2022 publication period. We extracted the databases reported in their methods sections. Web of Science, Scopus, Google Scholar, and ScienceDirect were the most frequently used, while other databases appeared less consistently (Fig. 2).

For this review, we selected Web of Science and Scopus as the primary databases because they provide broad multidisciplinary coverage and are frequently used in nexus scholarship. ScienceDirect was not used as a primary database, consistent with previous reviews that have noted its comparatively limited coverage for resource nexus searches and the underrepresentation of relevant journal special issues. Google Scholar was used in a supplementary manner to refine search strategy. Other databases were not prioritised because they offered narrower coverage and yielded limited additional retrieval for the nexus topic relative to Web of Science and Scopus.

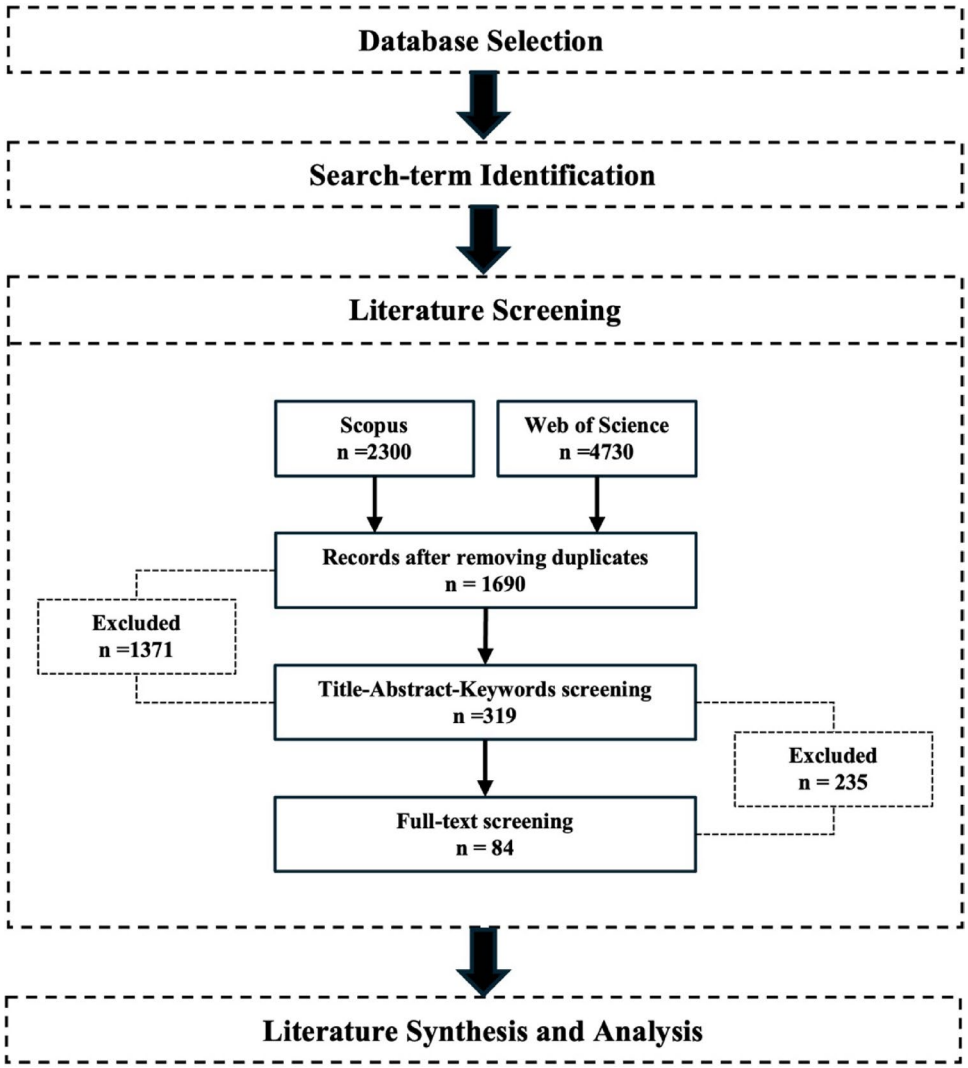

Fig. 1 Overview of the review process

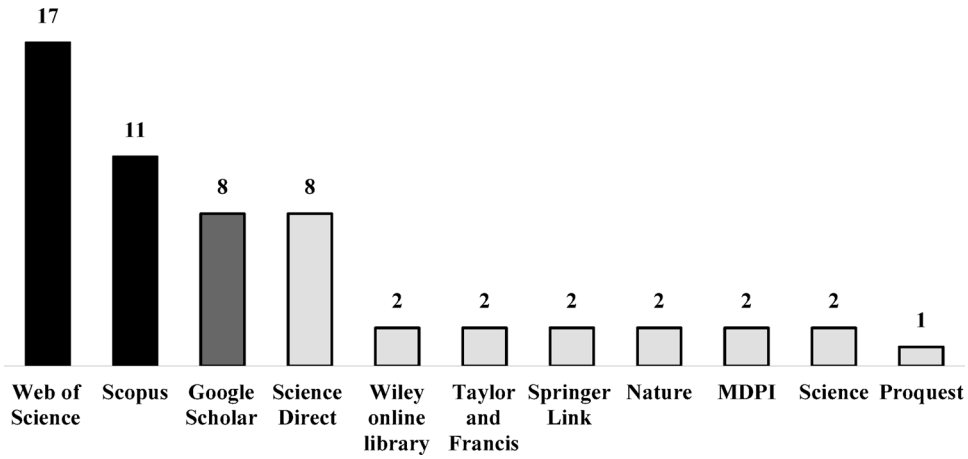

Fig. 2 The frequency of database use in 27 systematic reviews

2.2 Search terms identification

Next, we identified developed a comprehensive search-term vocabulary. We began by extracting and classifying nexus-related keywords and search terms reported in the 27 review articles examined in the previous stage. To broaden this initial pool, we screened an additional 185 research articles and book chapters retrieved from Google Scholar and extracted relevant key words and terminology. Terms from both sources were compiled, assessed for relevance and

specificity, and the most frequently occurring terms were shortlisted for further refinement.

Building on this nexus vocabulary, we developed two additional term sets to capture aspects of social and demographic change. These sets were expanded through synonym mapping and related terms identified in the literature. We then tested and refined the combined term sets iteratively using Boolean operators, evaluating alternative combinations to optimise retrieval of relevant studies from Web of Science and Scopus. Full search strings and term sets are provided in the Supplementary Materials.

2.3 Literature screening and analysis

The third stage, literature screening, was conducted in three phases: database screening, Title-Abstract-Keywords screening, and full-text screening. During database screening, we limited results to peer-reviewed journal articles and book chapters published between November 16, 2011, and August 26, 2022. This window captures the period from the consolidation and popularisation of the resource nexus concept following the 2011 Bonn Conference through to the planning stage of this review. Searches were restricted to English-language publications, and no thematic or geographic filters were applied. In total, 7,030 records were retrieved (4330 from Web of Science and 2300 from Scopus).

Title-abstract-keywords screening was conducted in *Rayyan*, a web-based platform designed to support systematic review screening and documentation (Ouzzani et al. 2016). *Rayyan* was used to import and organise records, facilitate coordination during the initial screening, and record exclusion decisions to enhance transparency and reproducibility. The complete screening library can be accessed through the Supplementary Materials.

In this phase, duplicates were removed and records not meeting the inclusion criteria were excluded. Exclusion criteria included: publications outside the selected timeframe; non-peer-reviewed materials; books and reports; non-English publications; thematically irrelevant studies; studies that did not address socio-demographic change in the context of nexus research; studies lacking a nexus, systems, or integrative perspective on land-food-water-energy resources; and studies engaging with fewer than two nexus sectors. Bibliometric analyses and literature reviews were also excluded to maintain a focus on empirical, case-study-based evidence and substantive findings. This process resulted in the exclusion of 1371 records.

Next, we conducted full-text screening of the 319 publications that passed the title-abstract-keywords stage. A further 235 records were excluded, primarily because they (1) emphasised methodological development with limited substantive results, (2) did not establish explicit linkages between resource nexus interactions and socio-demographic issues, (3) mentioned socio-demographic factors only superficially, or (4) treated land, food, water, and energy sectors in isolation rather than analysing their interconnections. Ultimately, 84 publications met the eligibility criteria and were retained for synthesis and analysis.

In the final stage, we synthesised and analysed the selected literature by constructing a literature matrix to support systematic comparison across studies. The matrix was designed to capture eight aspects: (1) publication details (title and full reference); (2) geographic focus; (3) spatial scale(s) of analysis; (4) scale(s) of anthropogenic interaction; (5) the resource nexus examined; (6) nexus sectors emphasised; (7) a contextual summary characterising the relationship between the resource nexus and socio-demographic change; and (8) the key socio-demographic challenges identified in each study. The completed literature summary matrix is provided in the Supplementary Materials.

3 Results

3.1 Geographic focus of studies

Figure 3 illustrates that nexus research exhibits a broad but uneven spatial dispersion across regions. Of the five major global regions (Africa, the Americas, Asia, Europe, and Oceania), Asia emerged as the predominant geographic focus in examined studies, with East Asia leading significantly in the number of case studies ($n=30$). Studies conducted in China, in particular, accounted for the largest share ($n=26$), both regionally and globally, meanwhile, Japan and Taiwan each contributed a single study to this body of literature. South Asia also showed substantial representation ($n=10$), with a significant focus on India ($n=7$). In contrast, Central and West Asia were critically underrepresented, with Central Asia covered by only two case studies and West Asia by a single study addressing Jordan and Lebanon. South-East Asia presented a modest contribution with three studies, two of which focused on the same region in Indonesia.

In Africa, aside from one study that addressed the continent as a whole, the majority of studies were focused on the Sub-Saharan region, while North Africa contributed a single study. Sub-Saharan Africa exhibited the broadest geographic range among all regions, spanning eight different countries. Ethiopia emerged as the primary focus with six studies, while Uganda was the subject of two studies. Other countries in Sub-Saharan Africa were represented by single studies. North Africa's sole study focused on the case of Egypt.

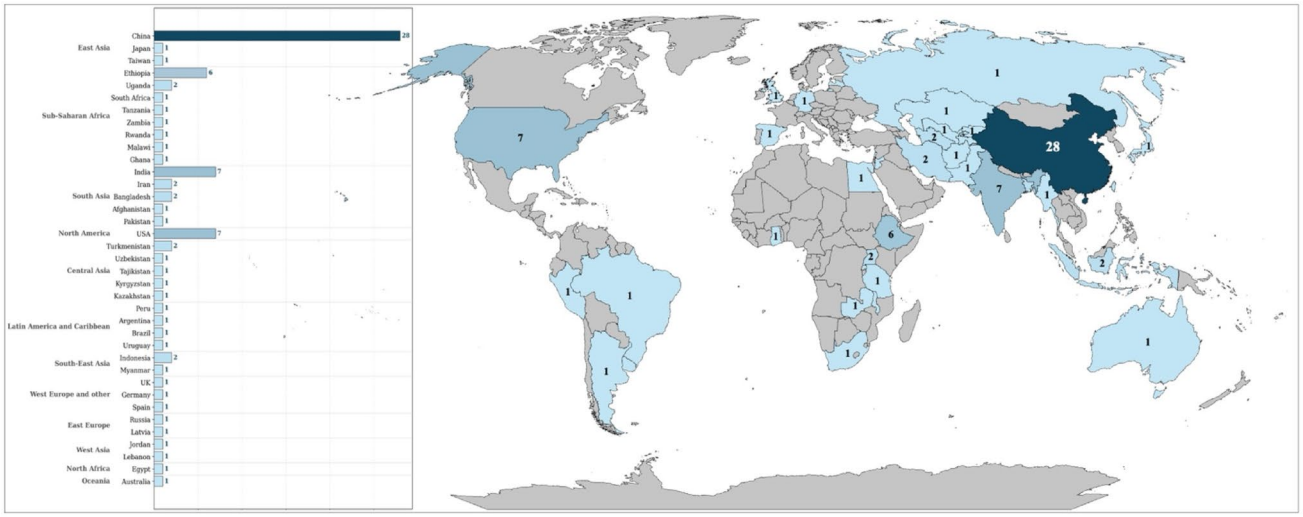

Fig. 3 Geographic distribution of selected studies ($n=78$ out of 84). The figure's count includes studies covering multiple countries as well as compound or cross-geographic analyses, excluding those conducted at the global scale ($n=6$)

Asia and Africa surpassed North America, South America, and the Caribbean in terms of research volume. North America contributed seven studies to the corpus, all of which were exclusively centred on the United States. In comparison, Latin America and the Caribbean recorded four studies, slightly fewer than North America, but with a broader geographical scope. Of these studies, one addressed the entire Latin American and Caribbean region, while the remaining three were focused on Uruguay, Argentina, and Peru.

Europe was the subject of five comprehensive studies in total. Of these, one featured a multi-regional analysis, while another focused specifically on West Europe, with Germany as its focal point. A third study examined the implications of Brexit in the United Kingdom and North Europe, while a separate study featured a partial investigation of Spain in South Europe. Another study focused on Latvia in East Europe.

Oceania recorded the lowest count regionally, with a single study focused on Australia.

Results also brought attention to studies conducted in various geographic contexts. Three studies focused on cross-national analyses, specifically examining cross-border river basins in Central and South Asia (Zhang et al. 2021; Wada et al. 2019). Other studies expanded their scope to cross-regional perspectives, with particular emphasis on the MENA region in two instances (Lange et al. 2016; Rogers 2017). Another study investigated the BRICS nations as a unified cluster (Ozturk 2015), while a separate study featured a comparative study of the four regions of Europe (Kebede et al. 2021). And a total of six studies undertook a comprehensive global-scale analysis (e.g., Lundqvist et al. 2015; Sušnik 2015; Jose Ibarrola-Rivas 2018), which also shows the wide-ranging scope of geographical exploration within the corpus of nexus studies.

3.2 Scales of analysis and anthropogenic activities

To better characterise the geospatial dimensions of the selected studies, we examined which spatial scales have been most and least explored in the nexus literature. We distinguished between two conceptual scales. The scale of analysis refers to the spatial extent at which each study frames evidence and evaluates processes. The scale of anthropogenic activities refers to the spatial footprint of human interventions and pressures assessed in each study, as well as their associated impacts. These include agricultural production and irrigation, water abstraction and management, energy generation and extraction including related infrastructure, industrial production and resource use, and urban land use change and infrastructure expansion, etc… Crucially, the scale of anthropogenic activities indicates the actual scale of the human interventions and pressures under examination, which may differ significantly from the scale at which studies conduct their analysis; therefore, a distinction has to be made between these scales to avoid conflating the spatial extent of inference with the spatial footprint of the underlying human activities as represented in nexus interactions.

The scales of analysis encompassed nine spatial levels, ranging from individual to the global level (Fig. 4a). Among the selected studies, national and sub-national scales emerged as the most frequently examined spatial scales. A notable number of studies ($n=18$) focused on basin-level analysis, slightly exceeding those that focused on local scales ($n=15$). Meanwhile, only a limited number of

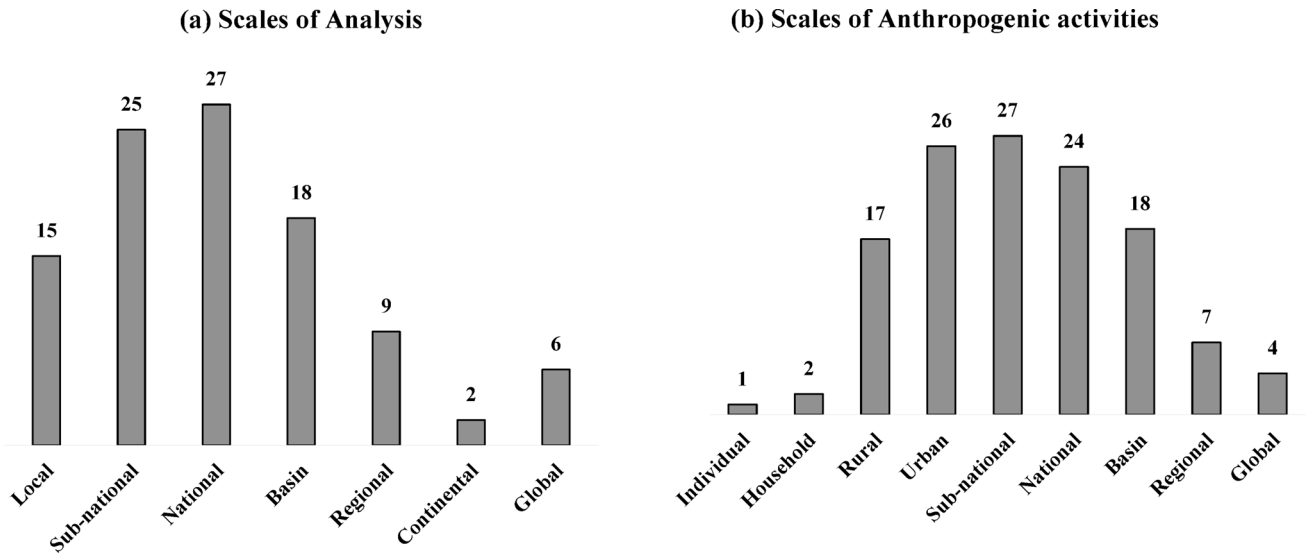

Fig. 4 Spatial scales of analysis (**a**) and anthropogenic activities (**b**) in selected studies

studies extended their scope to larger spatial scales, including regional, continental, and global scales.

In examining the scales of anthropogenic activities, a broader range of scales was considered (Fig. 4b). The majority of studies reflect a particular focus on human activities taking place at the sub-national ($n=27$), Urban ($n=26$), and National ($n=24$) scales. A significant number of studies explored interactions taking place at the basin level ($n=18$) and within rural areas ($n=17$). By contrast, relatively limited attention was directed towards anthropogenic activities at both the micro-scale (i.e., household and individual levels) and macro-scale (i.e., regional and global levels).

It is worth noting that a remarkable number of studies adopted a multi-scalar perspective on socio-demographic challenges by focusing on more than one spatial perspective, both for the scale of analysis and anthropogenic activities. Notably, a total count of nine studies undertook an explicit multi-scale analysis, while a larger count ($n=35$) examined anthropogenic interactions across multiple spatial levels. Equally noteworthy is the absence of studies addressing the complex impacts and challenges associated with trade and tele-connected nexus issues, which involve interactions across geographically distant but functionally interconnected systems.

3.3 Resource nexus

Analysis of resource interconnections revealed a predominant focus on the tripartite nexus Water-Food-Energy ($n=56$). Broader perspectives that included Water-Food-Energy-Land resources were moderately covered, with a total of eight studies addressing the full spectrum. Other combinations, such as Water-Energy-Land ($n=8$) and Food-Water ($n=4$), were also underrepresented. A total of three studies focused on the Food-Water-Land nexus, while two other studies examined the nexus of Land-Water. Both Energy-Food and Water-Energy interlinkages were each addressed once.

In terms of sectoral focus, the water sector was by far the primary emphasis in a significant number of studies ($n=23$) compared to other sectors, such as energy and land, which received considerably less attention (Fig. 5). The majority of selected studies ($n=54$), however, tended to give equal consideration to the whole spectrum of sector interactions under examination.

The remarkable emphasis on the water sector stems primarily from the substantial proportion of studies focusing on basin level interactions. Indeed, a closer examination reveals that nearly half of these water-focused studies employed analytical methodologies or investigated anthropogenic interactions within basin-level contexts. This suggests that the prominence of the water sector is driven by its critical role in localized nexus dynamics and its susceptibility to human interventions at smaller spatial scales.

3.4 Socio-demographic challenges

Analysis of nexus-related socio-demographic challenges revealed a wide array of factors (Fig. 6). Population growth and economic development emerged as the most dominant challenges, accounting for more than half of the studies reviewed. Urbanization ($n=22$) and dietary and lifestyle and changes ($n=19$) were also prominently addressed. Interestingly, issues related to policy development and policy change ($n=17$) were substantively represented, albeit not to the extent of population growth and economic development.

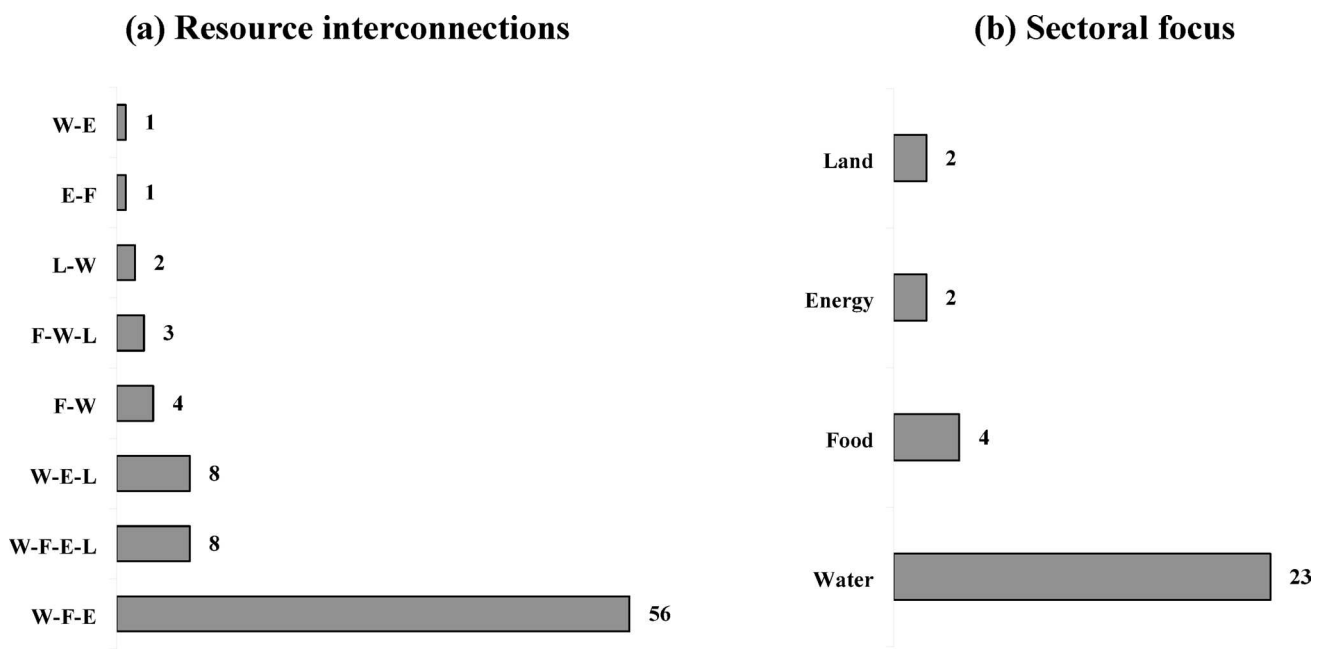

Fig. 5 Resource interconnections (**a**) and sectoral focus (**b**) in the selected nexus studies

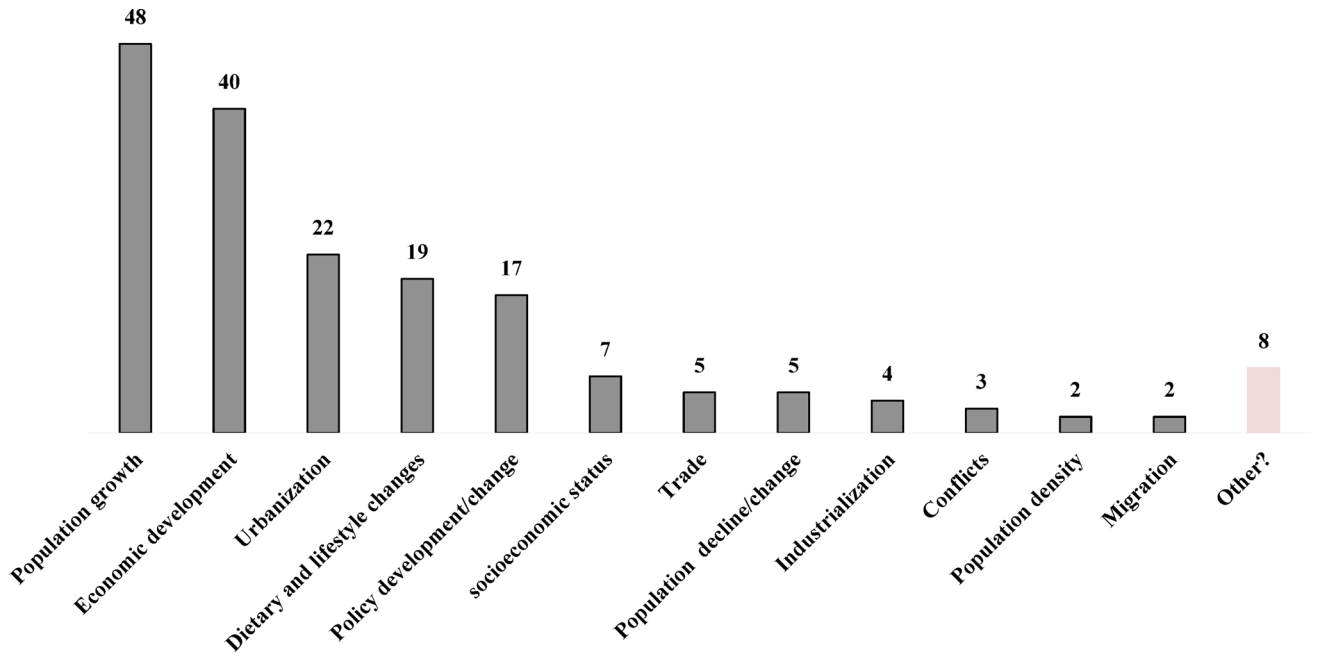

Fig. 6 Socio-demographic challenges

Additional challenges identified included socioeconomic status, trade activities, and industrialization, which were addressed in a modest number of studies ($n=7$, $n=5$, and $n=4$, respectively).

Strikingly, aside from population growth, other aspects of demographic change such as migration, population density, and population decline were remarkably underrepresented in the literature. While population change/decline was addressed in five studies, this remains modest in comparison to other challenges. Migration and population density-related challenges were even less emphasized, with only two studies each addressing these aspects.

Studies framed in the context of resource-based conflicts were also significantly underrepresented compared to the other socio-demographic factors. Only three studies were identified that addressed regional conflicts arising from competitive resource use and scarcity, particularly water resources. These studies focused primarily on cross-national

resource conflicts. Zhang et al. (2021) examined the impact of socioeconomic change and population growth in Central Asia's Aral Basin, highlighting how strained water resources have affected the energy and food sectors and contributed to conflicts among the neighbouring countries: Uzbekistan, Tajikistan, Kyrgyzstan, Kazakhstan, and Turkmenistan. Wada et al. (2019) proposed a nexus modelling framework that engages regional stakeholders from India, Pakistan, Afghanistan, and China to address existing and potential disputes over water resource allocation in the Indus River Basin in South Asia. Fowler and Shi (2016), on the other hand, focused on conflict resolution methodologies, particularly mediation processes, and provided several case studies in the U.S that ranged from site-specific project disputes to broader issues of natural resource planning and post-disaster recovery conflicts.

3.5 Geographic outlook on socio-demographic issues

Viewed through regional lenses, the examined literature reveals distinct patterns of socio-demographic challenges characteristic to each geographic area. In East Asia, namely China, challenges related to national and regional economic development ($n=18$) and population growth ($n=17$) were the most frequently addressed in studies. Urbanization ($n=13$) was also significantly discussed, while issues related to consumption patterns and lifestyle changes were only minimally addressed in five studies.

In Sub-Saharan Africa, the primary challenges identified were population growth ($n=7$) and policy development ($n=6$). Fewer studies explored challenges related to socioeconomic development, urbanization, and dietary and lifestyle changes. Most of the studies that touched upon policy challenges came in the context of the impacts of top-down hydropower dam policies in Ethiopia (e.g., Müller-Mahn and Gebreyes 2019; Gebreyes et al. 2020; Wolde et al. 2021).

In South Asia, 60% of the studies focused on challenges related to population growth in the first place. Half of these were exclusively centred on India. A considerable share of studies also highlighted the prevalence of nexus challenges related to resource consumption and lifestyle changes, most of which focused also on India. Other challenges, such as urbanization, economic development, policy changes, and socioeconomic disparities, were discussed but lacked clear geo-specific characteristics across the region.

Interestingly, studies in North America and Europe, along with the sole study that focused on Japan in East Asia, were the only ones to touch upon challenges related to population decline. Studies conducted in Europe (Bao et al. 2021; Ziv et al. 2018) offered limited insights into the implications of population change on the resource nexus, but did not engage in depth with the direct implications of Population decline. In contrast, some studies in North America examined population challenges at a more detailed spatial level. A good example of this is a workshop-based study by Treemore-Spears et al. (2016) that investigated the case of demographic and socioeconomic decline in two post-industrial U.S cities, Detroit and Baltimore. The study argued that the dramatic socioeconomic and demographic shifts the two cities have undergone over the past decades have led to severe degradation of water-energy-food/waste nexus infrastructure, and identifies key areas for intervention, including governance, racial justice, integrative metrics, and land transformation. Meanwhile, the single case study on Japan (Fujii and Sawadate 2018) explored the feasibility of small hydropower systems within the Energy-Food nexus and emphasized how a declining local population limits suitable sites for installations, ultimately hindering local transitions to sustainable energy production.

Studies in Latin America and the Caribbean focused predominantly on resource governance and scenario-based economic and climate policies. These included an analysis of economic policies in Uruguay (Khan et al. 2020), urban-rural resource management in Peru (Salmoral et al. 2020), and a regional analysis of the implications of biofuel production on the Land-Water nexus under future policy scenarios (Zhong et al. 2021).

The South-East Asian context highlighted challenges related to population growth and economic development. Two studies in Indonesia presented a rare case of follow-up research. The first (Purwanto et al. 2021b) developed a qualitative model of the Water-Energy-Food nexus specific to the Karawang regency, while the follow-up study (Purwanto et al. 2019) used this model to analyse policy interventions. In Myanmar, a study (Kattelus et al. 2013) examined the social and environmental risks to water, energy, and food security stemming from recent economic and political reforms targeting foreign investment in energy and agriculture.

In North Africa, the only case study recorded in Egypt (Lange et al. 2016) examined how population growth and urbanization contribute to land fragmentation, reducing the efficiency of the food sector and limiting climate adaptation capacity. Urbanization and high population density were identified as major challenges to achieving food self-sufficiency despite the relatively high crop productivity.

Almost all the studies conducted in the global context focused primarily on challenges related to population growth, resource consumption and lifestyle transitions. To cite an example, Jose Ibarrola-Rivas (2018) present a global analysis of the implications of population growth, socioeconomic factors, and dietary changes on the global nexus of Land-Water-Food resources. This research raises

critical questions about national resource sufficiency and the capacity of land- and water-constrained countries to meet the changing and growing demands of burgeoning populations. Key findings reveal significant shifts in food demand driven by population growth, resulting in diminished per capita land and water availability. The study emphasizes the necessity of transitioning to basic diets to mitigate these constraints, especially under a business-as-usual scenario that poses severe challenges to global food security.

An interesting study by Lundqvist et al. (2015) further argues that the global food crisis stems primarily from inefficiencies within the food system, which are largely due to changing consumer behaviours and demands. The research stresses the role of increasing affluence in shaping consumption patterns, which in turn leads to overconsumption and a growing preference for resource-intensive diets, particularly those rich in animal products. To address these challenges, Lundqvist et al. (2015) propose three global approaches: (1) a geographic expansion of agricultural production, (2) an intensification of existing food systems, and/or (3) reducing waste while promoting sustainable consumption practices. The authors dismiss the first two options as unsustainable and advocate for the third approach, which focuses on minimizing waste and fostering behavioural change. The study concludes with a call to align food security strategies with natural resource limitations and environmental conservation, stressing the critical need for societal shifts in attitudes, education, and the promotion of gender equality.

4 Discussion

In their book "*Want*, *Waste*, *War?"*, Andrews-Speed et al. (2014) propose a compelling framework for understanding contemporary global resource struggles as driven by converging anthropogenic forces of human demand (*Want*), systemic *Waste*, and resource-related conflict (*War*). These forces are deeply rooted in the demographic transitions, societal change, environmental pressures, and geopolitical conditions that shape resource interdependencies and governance. This framing resonates with the findings of this review, which highlight the centrality of socio-demographic and geographic contexts for interpreting resource nexus dynamics. In what follows, we synthesise the key insights and gaps identified across the reviewed literature and outline pathways for advancing the nexus from a conceptual framework towards a more actionable paradigm.

4.1 Critical gaps in socio-demographic and geographic contexts

An evident tendency in the reviewed literature is to treat population growth in developing countries as the primary driver of resource challenges. While this emphasis has generated valuable contributions, it has also tended to marginalise other socio-demographic factors, including socioeconomic change, consumption behaviours, migration, and geopolitical conditions. This framing can overstate the centrality of population growth in shaping global resource security. In practice, resource pressures emerge from more complex configurations in which lifestyle and behavioural change, together with geopolitical and environmental contexts, may be equally or more important in both developing and developed countries (Andrews-Speed et al. 2014; Gavinet, 2019).

Consistent with this imbalance, few studies have examined the effects of socioeconomic uplift on consumer attitudes and communal resource dynamics. Even fewer have addressed changing consumption patterns and lifestyle transitions in rapidly transforming economies such as China and India (e.g., Boyer and Ramaswami 2017; He et al. 2021). Existing efforts also remain constrained both in scope and geographic coverage. As globalisation increasingly exposes more of the developing world's populations to resource intensive modes of production and consumption, greater attention to behavioural change and its implications for community structures becomes critical. This points to a need for broader research that engages diverse socio-economic trajectories, social norms, and lifestyles in order to better capture the recursive links between societal change and resource challenges.

A further consequence of the population growth focus is the limited engagement with the ongoing global demographic transition. With global population growth slowing down after decades of rapid expansion (Dorling 2021), a growing number of countries are joining the ranks of already-depopulating nations, or soon-to-be. Despite substantial evidence of this trend, it remains largely absent from nexus discussions of resource security. Population decline, now an evident reality for both developed and developing nations, has been insufficiently explored in nexus literature. Only a small number of case studies in post-industrial settings in Europe, North America, and East Asia address this concern, leaving the broader consequences of this transition largely unexplored, particularly in countries like Japan, where depopulation has become a nationwide concern (Tsutsumi 2021; Inoue et al. 2021; Barrahmoune et al. 2026; Barrahmoune and Matanle 2026). Many South American countries, including Brazil, Uruguay, Chile, Costa Rica, Mexico, and Argentina, now experience fertility rates

below replacement levels. Similar trends are evident across East Asia and Europe and are increasingly observed in the world's most populous nations, China and India. Even sub-Saharan African countries, historically characterized by higher fertility, are experiencing declines in total fertility rates (UNPD 2024). Given these trajectories, the implications of population decline for resource systems and nexus governance remain an open empirical question that warrants more attention.

Migration-related challenges constitute another underexplored area. As both a driving force for change and a response to societal, demographic, environmental, and resource pressures, human migration exemplifies the complex interplay of global systems (Hugo 2008; Neumann and Hilderink 2015). The increasing frequency of climate-induced displacement highlights the accelerating impacts of environmental changes, including rising sea levels, drought, habitat loss, and extreme weather events (Daszak et al. 2001; Warner et al. 2009; Piguet et al. 2011; Moore and Wesselbaum 2022; Ripple et al. 2023). In the Pacific Islands, for instance, rising sea levels have forced entire communities to relocate, leading to increased competition over land, food, and water resources and essential infrastructure (Arnell 2004; Maclellan 2012; Mimura 2013; Borràs 2016; Kupferberg 2021). Migration also intersects with resource related conflicts, such as those driven by water scarcity, land disputes, and geopolitical tensions (Burrows and Kinney 2016). Despite its relevance to resource governance and adaptation, migration remains insufficiently integrated into nexus research. Future work should examine its dual role as both a contributor to, and an outcome of, resource stress, and trace its cascading effects across scales to inform strategies for managing displacement, mitigating resource competition, and strengthening resilience.

Conflict-related challenges represent a further gap. This review identified only two documented cases of resource-based conflicts, both concentrated in South and Central Asia (see Wada et al. 2019; Zhang et al. 2021). Absent, however, are studies investigating armed disputes, geopolitical tensions, civil conflicts, and unrest in regions such as the Middle East, North and Sub-Saharan Africa, East Europe, South Asia, and Latin America. This absence constrains understanding of contexts where resource crises may act as both triggers and consequences of conflict, and where governance capacity is often structurally compromised. Several other critical issues also mark their absence. These include conflicts arising from Water-Energy-Food nexus infrastructure projects and upstream water disputes in the Middle East (Hameed et al. 2019; Mohamed 2018), ethnic land rights conflicts in Sub-Saharan Africa and Latin America (Bernstein 2005; Wegenast and Schneider 2017; Wong, 2019), and maritime boundary disputes in Southeast Asia and Europe (Hasan et al. 2019; Østhagen 2020). Equally significant are micro-scale tensions that take place in the everyday life of densely populated urban centres across South and Southeast Asia, Latin America and the Caribbean, and Sub-Saharan Africa, which also warrant more attention given their significant implications for everyday resource access and governance legitimacy. Addressing these gaps is essential for developing a more realistic account of nexus dynamics in conflict affected settings and for informing conflict sensitive strategies that recognise the cascading effects of resource insecurity on livelihoods and regional stability.

4.2 Geospatial considerations

Scaling the nexus remains a critical challenge for analysing and governing resource dynamics (McGrane et al. 2018; Vinca et al. 2021). Although "one-size-fits-all" approaches are widely recognised as ineffective (Cash et al. 2006), an exclusive reliance on context-specific case studies can limit transferability and reduce practical utility for broader governance agendas (Gibson et al. 2000). A balanced approach is therefore required, one that retains sensitivity to local conditions while situating them within wider systemic dynamics. Multi-scale and cross-scale methodologies provide a robust basis for achieving this balance (Wilbanks 2015; Barrahmoune et al. 2019; Paná et al. 2024).

The findings of this review indicate that nexus research has increasingly incorporated multi-scale perspectives, particularly by recognising that anthropogenic interventions and their effects operate across multiple spatial and governance levels. Several studies, including Müller-Mahn and Gebreyes (2019) and Kattelus et al. (2013), show how global and national power relations shape nexus interactions in local contexts. Others, such as Ziv et al. (2018), gave a clear example of how national policy changes, such as BREXIT, can cascade into regional and local resource dynamics through mutually reinforcing mechanisms.

From an analytical perspective, however, relatively few studies employ explicit multi-scale designs that systematically link processes and outcomes across levels. This underscores the need to further develop approaches that can trace interactions across geographical and governance scales and improve comparability across cases. Despite concerns that strongly coordinated governance may constrain self-organisation and innovation, and that multi-level analyses raise challenges for data integration (Pahl-Wostl 2009), multi-scalar approaches remain essential for both assessment and governance. They enable engagement with overlapping operative scales and support more robust interpretations of nexus dynamics (Vinca et al. 2020).

A related gap lies in the absence of cross-scalar or tele-connected considerations. Findings reveal that nexus

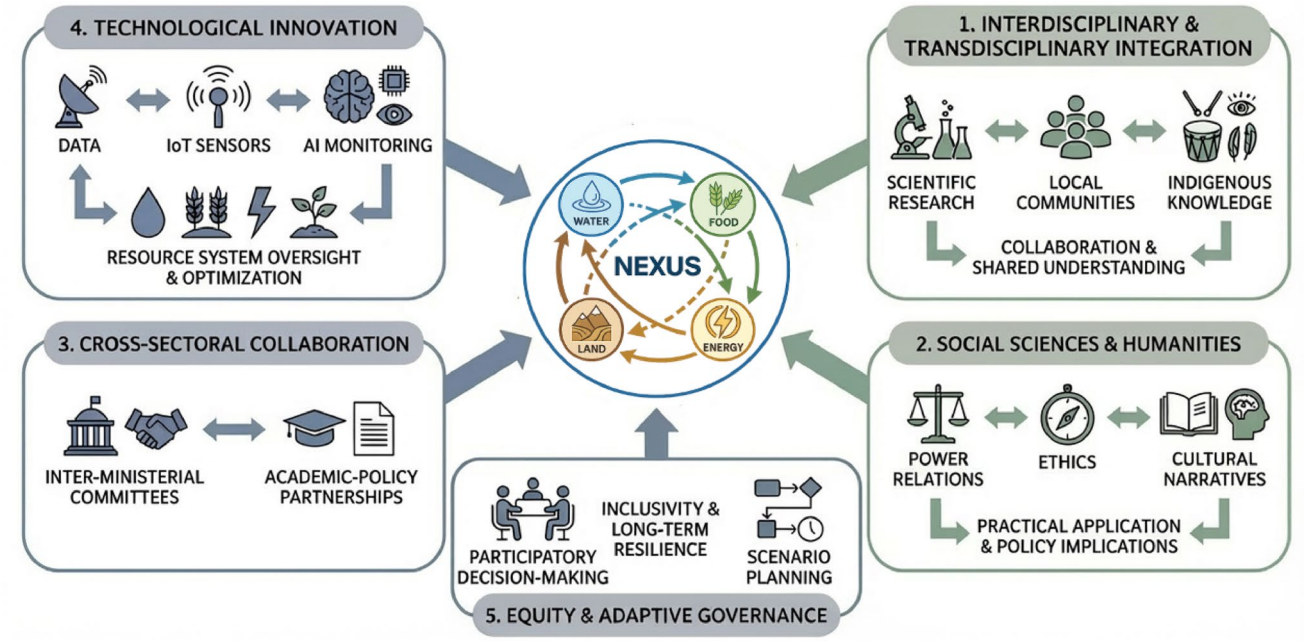

Fig. 7 A forward-looking vision for bridging the operational gap in resource nexus governance

research remains weakly integrated with frameworks that explicitly examine interactions across distant but functionally linked resource systems, such as the telecoupling framework (Zhang et al. 2019a, b; Liu 2023; Barrahmoune and Matanle 2026). Nexus interactions are clearly not geographically confined and extend far beyond local and regional scopes. The increasing intensity of trade, populations movements, and globalization of lifestyles and consumption patterns have added new layers of complexity to the cause-and-effect relationships between natural systems and socio-demographic challenges. Addressing these complexities requires focusing not only on proximate effects, but also to the wider, distributed consequences generated through interconnected systems.

4.3 Towards operative nexus governance

Transitioning the nexus from a conceptual framework to actionable strategies presents a host of management and governance challenges, particularly when accounting for the socio-demographic and geographic complexities that underpin resource systems. The nexus framework inherently recognises the synergies and trade-offs among water, food, land, energy, and other resource systems, highlighting how actions in one sector can reverberate across others (Pahl-Wostl 2019; Zare et al. 2020). However, effectively operationalising this framework requires navigating a range of interconnected challenges, including socio-political dynamics, geographic disparities, and cultural contexts, while also ensuring stakeholder inclusivity and adaptive governance (Fig. 7).

Advancing the operational aspects of nexus governance hinges on the effective integration of interdisciplinary and transdisciplinary methodologies. Interdisciplinary methodologies bring together insights from the natural and social sciences, offering a more holistic perspective on resource interdependencies and their governance implications (Zare et al. 2020). Transdisciplinary approaches can reinforce this foundation by engaging a broader range of actors, including local communities, policymakers, and businesses, in co-creating solutions that are tailored to specific socio-demographic and geographic realities (Pahl-Wostl 2009, 2019; Özcan et al. 2024). Combining scientific expertise with indigenous and traditional knowledge can further enrich governance strategies by reflecting diverse lived experiences and supporting culturally grounded and contextually relevant solutions (Brondízio et al. 2021; Yanou et al. 2023).

Social sciences and humanities are particularly central in bridging the gap between theoretical frameworks and real-world applications. Social sciences can contribute by providing critical insights into power relations, institutional arrangements, and behavioural patterns that shape resource use and governance outcomes (Wiegleb and Bruns 2018). Humanities scholarship can complement these contributions by elucidating cultural, ethical, and historical perspectives that situate resource challenges within broader societal narratives, thereby supporting more inclusive problem framing and communication strategies (Meireis and Rippl 2020).

Taken together, these disciplinary perspectives strengthen nexus governance by enabling resource interdependencies to be addressed in ways that are simultaneously social, technical, and environmental.

Effective governance also demands reconciling competing objectives, including economic development, social equity, and environmental conservation. This, in turn, underscores the need to move beyond siloed management and policymaking in favour of cross-sectoral collaboration. Integrated platforms such as inter-ministerial committees, public private partnerships, academic policy collaborations, and community-based networks provide mechanisms for facilitating cooperation and inclusive participation by enabling cross-sectoral dialogue, aligning objectives, and making synergies and trade-offs explicit (Boas et al. 2016; Özcan et al. 2024; Yadav and Singh 2024). Illustrative examples can be found in collaborative initiatives in the Nile Basin and Central Asia, where efforts to address water disputes underscore the importance of integrating regional, national, and local actors to reconcile competing interests and support equitable and sustainable resource governance (Cascão and Nicol 2016; Wada et al. 2019; Müller-Mahn and Gebreyes 2019). In this respect, nexus governance holds potential not only to mitigate conflict, but also to enhance the scalability of solutions through trust building and accountability among stakeholders.

Technological innovation can further support nexus governance by enabling more timely monitoring and predictive modelling of resource systems. Tools such as satellite imagery, Internet of Things (IoT) devices, and artificial intelligence can generate actionable information for anticipating and responding to cascading effects across resource sectors (McGrane et al. 2018; Smajgl 2021; Mana et al. 2022; Zaitchik et al. 2022). Data and information gaps, however, must be addressed through investments in data infrastructure, capacity building, and open access platforms. Such efforts are necessary to broaden access to reliable data, reduce exclusivity in decision-making, and support inclusive governance, particularly in developing and resource-scarce regions (Huning et al. 2024).

Lastly, equity must remain at the core of nexus governance, ensuring that policies do not disproportionately burden marginalised communities or reinforce existing inequalities. Minority-inclusive approaches and participatory decision-making frameworks are key to addressing systemic imbalances by ensuring that underrepresented groups have a meaningful role in shaping resource strategies and governance processes (Agyeman et al. 2002; Turner et al. 2016; Jalonen et al. 2022). Adaptive management and scenario planning are equally important, as they emphasise flexibility and iterative learning to navigate the uncertainties inherent in socio-demographic and environmental change (Benson 2011; Golfam et al. 2021; Basheer et al. 2023; Ni and Chen 2024).

5 Conclusion

This review synthesizes evidence on the treatment of socio-demographic and geographic context in resource nexus research and identifies key limitations in the literature. A key limitation is the tendency to treat population growth as the principal driver of nexus challenges, which can obscure other consequential dynamics including population decline, migration, resource-related conflict, and interdependencies that operate across places and scales. These findings indicate the need to move nexus scholarship beyond predominantly conceptual framings towards more operational approaches that explicitly incorporate geographic and socio-demographic context.

Progress in this direction requires integrative approaches that synthesise interdisciplinary evidence, enable collaborative governance, and support adaptive decision-making under changing conditions. Greater engagement with the social sciences and humanities, alongside technical and technological innovation, can strengthen the nexus paradigm's capacity to produce analyses and interventions that are contextually grounded and attentive to distributional and equity implications. Such shifts are central to responding to the socio-demographic and geographic pressures shaping resource governance, and to supporting more integrative and sustainable pathways forward.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00550-026-00589-1.

Author contributions Anass Barrahmoune conceived the ideas, collected data, conducted the analysis, wrote the original draft, and led the review and editing process. Peter Matanle provided supervision and contributed to the review and editing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Declarations

Conflict of interest We declare no potential conflicts of interest with respect to the research, authorship, and publication of this article.

References

Agyeman J, Bullard RD, Evans B (2002) Exploring the nexus: bringing together sustainability, environmental justice and equity. Space Polity 6(1):77–90. https://doi.org/10.1080/13562570220137907

Albrecht TR, Crootof A, Scott CA (2018) The water-energy-food nexus: a systematic review of methods for nexus assessment. Environ Res Lett 13(4):043002. https://doi.org/10.1088/1748-9326/aaa9c6

Andrews-Speed P, Bleischwitz R, Boersma T, Johnson C, Kemp G, VanDeveer SD (2014) Want, waste or war?: The Global Resource Nexus and the struggle for land, energy, food, water and minerals. Routledge, Abingdon, Oxon

Arnell NW (2004) Climate change and global water resources: SRES emissions and socio-economic scenarios. Glob Environ Change 14(1):31–52. https://doi.org/10.1016/j.gloenvcha.2003.10.006

Arthur M, Liu G, Hao Y, Zhang L, Liang S, Asamoah EF, Lombardi GV (2019) Urban food-energy-water nexus indicators: a review. Resour Conserv Recycl 151:104481. https://doi.org/10.1016/j.resconrec.2019.104481

Bao K, Padsala R, Coors V, Thrän D, Schröter B (2021) A GIS-based simulation method for regional food potential and demand. Land 10(8):880. https://doi.org/10.3390/land10080880

Barrahmoune A, Lahboub Y, El Ghmari A (2019) Ecological footprint accounting: a multi-scale approach based on net primary productivity. Environ Impact Assess Rev 77:136–144. https://doi.org/10.1016/j.eiar.2018.12.003

Barrahmoune A, Matanle P, Kim J (2026) Does human depopulation reduce resource consumption? Evidence from anthropocene Japan. Sustain Sci. https://doi.org/10.1007/s11625-025-01775-8

Barrahmoune, A., & Matanle, P. (2026). Changes in Japan's food consumption footprints under human depopulation. Cleaner and Responsible Consumption, 21, 100418 https://doi.org/10.1016/j.clrc.2026.100418

Basheer M, Nechifor V, Calzadilla A, Gebrechorkos S, Pritchard D, Forsythe N, Gonzalez JM, Sheffield J, Fowler HJ, Harou JJ (2023) Cooperative adaptive management of the Nile River with climate and socio-economic uncertainties. Nat Clim Change 13(1):48–57. https://doi.org/10.1038/s41558-022-01556-6

Benson MH (2011) Adaptive management as a tool for negotiating the water–energy nexus. Water–Energy Nexus Am West. https://doi.org/10.4337/9781849809375.00026

Bernstein H (2005) Rural Land and Land Conflicts in Sub-Saharan Africa. Reclaiming the Land: The Resurgence of Rural Movements in Africa, Asia and Latin America. Zed Books, pp 67–101

Bleischwitz R, Spataru C, VanDeveer SD, Obersteiner M, van der Voet E, Johnson C, Andrews-Speed P, Boersma T, Hoff H, van Vuuren DP (2018) Resource nexus perspectives towards the United Nations Sustainable Development Goals. Nat Sustain 1(12):737–743. https://doi.org/10.1038/s41893-018-0173-2

Boas I, Biermann F, Kanie N (2016) Cross-sectoral strategies in global sustainability governance: towards a nexus approach. Int Environ Agreements: Politics, Law Econ 16(3):449–464. https://doi.org/10.1007/s10784-016-9321-1

Borge-Diez D, García-Moya FJ, Rosales-Asensio E (2022) Water energy food nexus analysis and management tools: a review. Energies 15(3):1146. https://doi.org/10.3390/en15031146

Borràs S (2016) Migration with dignity for climate justice: The situation of small island developing states. The Common Good and Ecological Integrity. Routledge, pp 239–254

Boyer D, Ramaswami A (2017) What is the contribution of city-scale actions to the overall food system's environmental impacts? Assessing water, greenhouse gas, and land impacts of future urban food scenarios. Environ Sci Technol 51(20):12035–12045. https://doi.org/10.1021/acs.est.7b03176

Brondízio ES, Aumeeruddy-Thomas Y, Bates P, Carino J, Fernández-Llamazares Á, Ferrari MF, Galvin K, Reyes-García V, McElwee P, Molnár Z, Samakov A, Shrestha UB (2021) Locally based, regionally manifested, and globally relevant: Indigenous and local knowledge, values, and practices for nature. Annu Rev Environ Resour 46(1):481–509. https://doi.org/10.1146/annurev-environ-012220-012127

Brouwer F, Caucci S, Karthe D, Kirschke S, Madani K, Mueller A, Zhang L, Guenther E (2024) Advancing the resource nexus concept for research and practice. Sustain Nexus Forum 31(1–4):41–65. https://doi.org/10.1007/s00550-024-00533-1

Burrows K, Kinney P (2016) Exploring the climate change, migration and conflict nexus. Int J Environ Res Public Health 13(4):443. https://doi.org/10.3390/ijerph13040443

Cascão AE, Nicol A (2016) Sudan, "kingmaker" in a new Nile Hydropolitics: Negotiating water and hydraulic infrastructure to expand large-scale irrigation. Land and Hydropolitics in the Nile River Basin: Challenges and New Investments. Routledge, London, pp 89–116

Cash DW, Adger WN, Berkes F, Garden P, Lebel L, Olsson P, Pritchard L, Young O (2006) Scale and cross-scale dynamics: governance and information in a multilevel world. Ecol Soc. https://doi.org/10.5751/es-01759-110208

Daher BT, Mohtar RH (2018) Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making. Sustainability in the Water Energy Food nexus. Routledge, pp 36–59

Dai J, Wu S, Han G, Weinberg J, Xie X, Wu X, Song X, Jia B, Xue W, Yang Q (2018) Water-energy nexus: a review of methods and tools for macro-assessment. Appl Energy 210:393–408. https://doi.org/10.1016/j.apenergy.2017.08.243

Daszak P, Cunningham AA, Hyatt AD (2001) Anthropogenic environmental change and the emergence of infectious diseases in wildlife. Acta Trop 78(2):103–116. https://doi.org/10.1016/s0001-706x(00)00179-0

Dorling D (2021) World population prospects at the UN: our numbers are not our problem? struggle soc sustain. https://doi.org/10.51952/9781447356127.ch007

Endo A, Tsurita I, Burnett K, Orencio PM (2017) A review of the current state of research on the water, energy, and food nexus. J Hydrol Reg Stud 11:20–30. https://doi.org/10.1016/j.ejrh.2015.11.010

Endo A, Yamada M, Miyashita Y, Sugimoto R, Ishii A, Nishijima J, Fujii M, Kato T, Hamamoto H, Kimura M, Kumazawa T, Qi J (2020) Dynamics of water–energy–food nexus methodology, methods, and tools. Curr Opin Environ Sci Health 13:46–60. https://doi.org/10.1016/j.coesh.2019.10.004

Estoque RC (2023) Complexity and diversity of nexuses: a review of the nexus approach in the sustainability context. Sci Total Environ 854:158612. https://doi.org/10.1016/j.scitotenv.2022.158612

Fayiah M, Dong S, Singh S, Kwaku EA (2020) A review of water–energy nexus trend, methods, challenges and future prospects. Int J Energy Water Resour 4(1):91–107. https://doi.org/10.1007/s42108-020-00057-6

Fowler LB, Shi X (2016) Human conflicts and the food, energy, and water nexus: building collaboration using facilitation and mediation to manage environmental disputes. J Environ Stud Sci 6(1):104–122. https://doi.org/10.1007/s13412-016-0373-x

Fujii M, Sawadate T (2018) Assessment of potential small hydropower generation: a case study in Otsuchi, Iwate Prefecture, Japan. Global Environ Stud. https://doi.org/10.1007/978-981-10-7383-0_2

Ganivet E (2019) Growth in human population and consumption both need to be addressed to reach an ecologically sustainable future. Environ Dev Sustain 22(6):4979–4998. https://doi.org/10.1007/s10668-019-00446-w

Gebreyes M, Bazzana D, Simonetto A, Müller-Mahn D, Zaitchik B, Gilioli G, Simane B (2020) Local perceptions of water-energy-food security: livelihood consequences of dam construction in Ethiopia. Sustainability 12(6):2161. https://doi.org/10.3390/su12062161

Ghodsvali M, Krishnamurthy S, de Vries B (2019) Review of transdisciplinary approaches to food-water-energy nexus: a guide towards sustainable development. Environ Sci Policy 101:266–278. https://doi.org/10.1016/j.envsci.2019.09.003

Giampietro M (2018) Perception and representation of the resource nexus at the interface between society and the natural environment. Sustainability 10(7):2545. https://doi.org/10.3390/su10072545

Gibson CC, Ostrom E, Ahn TK (2000) The concept of scale and the human dimensions of global change: a survey. Ecol Econ 32(2):217–239. https://doi.org/10.1016/s0921-8009(99)00092-0

Golfam P, Ashofteh P-S, Loáiciga HA (2021) Modeling adaptation policies to increase the synergies of the water-climate-agriculture nexus under climate change. Environ Dev 37:100612. https://doi.org/10.1016/j.envdev.2021.100612

Hameed M, Moradkhani H, Ahmadalipour A, Moftakhari H, Abbaszadeh P, Alipour A (2019) A review of the 21st century challenges in the food-energy-water security in the Middle East. Water 11(4):682. https://doi.org/10.3390/w11040682

Hasan MM, Jian H, Alam MW, Chowdhury KM (2019) Protracted maritime boundary disputes and maritime laws. J Int Maritime Saf Environ Affairs Shipp 2(2):89–96. https://doi.org/10.1080/25725084.2018.1564184

He G, Geng C, Zhai J, Zhao Y, Wang Q, Jiang S, Zhu Y, Wang L (2021) Impact of food consumption patterns change on agricultural water requirements: an urban-rural comparison in China. Agric Water Manage 243:106504. https://doi.org/10.1016/j.agwat.2020.106504

Hejnowicz AP, Thorn JP, Giraudo ME, Sallach JB, Hartley SE, Grugel J, Pueppke SG, Emberson L (2022) Appraising the water-energy-food nexus from a sustainable development perspective: a maturing paradigm? Earth's Future. https://doi.org/10.1029/2021ef002622

Hoff H (2011) Understanding the nexus. In *Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus*. Stockholm Environment Institute, Stockholm. Available at: https://mediamanager.sei.org/documents/Publications/SEI-Paper-Hoff-UnderstandingTheNexus-2011.pdf

Hugo G (2008) Migration, development and environment. International Organization for Migration, Geneva

Huning LS, Bateni SM, Hayes M, Ho S-G, Jayasinghe S, Kumar R, Lima C, Love CA, Madani K, Markonis Y, Matin MA, Miao C, Motagh M, Naeger A, de Oliveira DY, Read LK, Samaniego L, Shokri N, Shukla S, Soltanian R, Stefanski R, Trabelsi F, Tsegai D, Vo LUC, Wanders N, Wens M, Zarei A, AghaKouchak A (2024) Sustainability nexus analytics, informatics, and data (AID): drought. Sustain Nexus Forum. https://doi.org/10.1007/s00550-024-00546-w

Inoue T, Koike S, Yamauchi M, Ishikawa Y (2021) Exploring the impact of depopulation on a country's population geography: lessons learned from Japan. Popul Space Place. https://doi.org/10.1002/psp.2543

Jalonen R, Zaremba H, Petesch P, Elias M, Estrada-Carmona N, Tsvuura S, Koirala S (2022) Gender equity and social inclusion in the water-energy-food-ecosystems (WEFE) nexus: Frameworks and tools for moving from resource-centric to people-centric WEFE nexus approaches, vol 28. Alliance of Bioversity International and International Center for Tropical Agriculture (CIAT), Rome (Italy)

Jose Ibarrola-Rivas M (2018) Is the available cropland and water enough for food demand? A global perspective of the land-water-food nexus. Sci Trends. https://doi.org/10.31988/scitrends.13116

Kaddoura S, El Khatib S (2017) Review of water-energy-food nexus tools to improve the nexus modelling approach for integrated policy making. Environ Sci Policy 77:114–121. https://doi.org/10.1016/j.envsci.2017.07.007

Kattelus, M., Rahaman, M. M., & Varis, O. (2013). Myanmar under reform: Emerging pressures on water, energy and food security. Natural Resources Forum, 38(2), 85–98 https://doi.org/10.1111/1477-8947.12032

Kebede AS, Nicholls RJ, Clarke D, Savin C, Harrison PA (2021) Integrated assessment of the food-water-land-ecosystems nexus in Europe: implications for sustainability. Sci Total Environ 768:144461. https://doi.org/10.1016/j.scitotenv.2020.144461

Khan Z, Wild TB, Silva Carrazzone ME, Gaudioso R, Mascari MP, Bianchi F, Weinstein F, Pérez F, Pérez W, Miralles-Wilhelm F, Clarke L, Hejazi M, Vernon CR, Kyle P, Edmonds J, Muñoz Castillo R (2020) Integrated energy-water-land nexus planning to guide national policy: an example from Uruguay. Environ Res Lett 15(9):094014. https://doi.org/10.1088/1748-9326/ab9389

Kupferberg JS (2021) Migration and dignity – relocation and adaptation in the face of climate change displacement in the Pacific – a human rights perspective. Int J Hum Rights 25(10):1793–1818. https://doi.org/10.1080/13642987.2021.1889515

Lange MA, Saab N, Deboos A, Saidam M, Jägerskog A, Boromisa A, Dasgupta S, Abdel-Monem M, Sarsak R, Abdelraouf M (2016) Climate change adaptation solutions for the green sectors of selected zones in the MENA region. In: *Adaptation to Climate Change in the Water Sector in the MENA Region*

Liu J (2023) Leveraging the metacoupling framework for sustainability science and global sustainable development. Natl Sci Rev. https://doi.org/10.1093/nsr/nwad090

Liu J, Hull V, Godfray HC, Tilman D, Gleick P, Hoff H, Pahl-Wostl C, Xu Z, Chung MG, Sun J, Li S (2018) Nexus approaches to global sustainable development. Nat Sustain 1(9):466–476. https://doi.org/10.1038/s41893-018-0135-8

Lundqvist J, Liu J, Lundberg J (2015) Consumers, food supply chain and the Nexus. Climate, Energy and Water. Cambridge University Press, pp 303–323. https://doi.org/10.1017/cbo9781139248792.018

Maclellan N (2012) Kiribati's policy for migration with dignity. *The Devpolicy Blog*. Available at: https://devpolicy.org/kiribati_migration_climate_change20120112

Mana AA, Allouhi A, Hamrani A, Jamil A, Ouazzani K, Barrahmoune A, Daffa D (2022) Survey review on artificial intelligence and embedded systems for agriculture safety: a proposed IoT Agro-meteorology System for Local Farmers in Morocco. Smart embedded systems and applications. CRC, pp 211–242

Mannan M, Al-Ansari T, Mackey HR, Al-Ghamdi SG (2018) Quantifying the energy, water and food nexus: a review of the latest developments based on life-cycle assessment. J Clean Prod 193:300–314. https://doi.org/10.1016/j.jclepro.2018.05.050

McGrane SJ, Acuto M, Artioli F, Chen P, Comber R, Cottee J, Farr-Wharton G, Green N, Helfgott A, Larcom S, McCann JA, O'Reilly P, Salmoral G, Scott M, Todman LC, van Gevelt T, Yan X (2018) Scaling the nexus: towards integrated frameworks for analysing water, energy and food. Geogr J 185(4):419–431. https://doi.org/10.1111/geoj.12256

Meireis T, Rippl G (2020) Cultural sustainability: Perspectives from the Humanities and Social Sciences. Routledge, Abingdon, Oxon

Meng F, Liu G, Liang S, Su M, Yang Z (2019) Critical review of the energy-water-carbon nexus in cities. Energy 171:1017–1032. https://doi.org/10.1016/j.energy.2019.01.048

Mimura N (2013) Sea-level rise caused by climate change and its implications for society. Proc Japan Acad Ser B 89(7):281–301. https://doi.org/10.2183/pjab.89.281

Mohamed NN (2018) Continuous dispute between Egypt and Ethiopia concerning Nile Water and mega dams. In *Grand Ethiopian Renaissance Dam Versus Aswan High Dam: A View from Egypt* (pp. 451–483). Springer. https://doi.org/10.1007/698_2017_209

Molajou A, Afshar A, Khosravi M, Soleimanian E, Vahabzadeh M, Variani HA (2021) A new paradigm of water, food, and energy nexus. Environ Sci Pollut Res 30(49):107487–107497. https://doi.org/10.1007/s11356-021-13034-1

Molefe T, Inglesi-Lotz R (2022) Examining the water–energy–food (WEF) nexus through an SDG lens for the big 5 African countries. Environ Dev Sustain 25(12):14083–14100. https://doi.org/10.1007/s10668-022-02650-7

Moore M, Wesselbaum D (2022) Climatic factors as drivers of migration: a review. Environ Dev Sustain 25(4):2955–2975. https://doi.org/10.1007/s10668-022-02191-z

Morales-García M, Rubio M (2023) Sustainability of an economy from the water-energy-food nexus perspective. Environ Dev Sustain 26(2):2811–2835. https://doi.org/10.1007/s10668-022-02877-4

Müller-Mahn D, Gebreyes M (2019) Controversial connections: the water-energy-food nexus in the Blue Nile Basin of Ethiopia. Land 8(9):135. https://doi.org/10.3390/land8090135

Namany S, Al-Ansari T, Govindan R (2019) Sustainable energy, water and food nexus systems: a focused review of decision-making tools for efficient resource management and governance. J Clean Prod 225:610–626. https://doi.org/10.1016/j.jclepro.2019.03.304

Neumann K, Hilderink H (2015) Opportunities and challenges for investigating the environment-migration nexus. Hum Ecol 43(2):309–322. https://doi.org/10.1007/s10745-015-9733-5

Newell JP, Goldstein B, Foster A (2019) A 40-year review of food–energy–water nexus literature and its application to the urban scale. Environ Res Lett 14(7):073003. https://doi.org/10.1088/1748-9326/ab0767

Ni Y, Chen Y (2024) Does the implementation sequence of adaptive management countermeasures affect the collaborative security of the water-energy-food nexus? A case study in the Yangtze River Economic Belt. Ecol Indic 163:112090. https://doi.org/10.1016/j.ecolind.2024.112090

Opejin AK, Aggarwal RM, White DD, Jones JL, Maciejewski R, Mascaro G, Sarjoughian HS (2020) A bibliometric analysis of food-energy-water nexus literature. Sustainability 12(3):1112. https://doi.org/10.3390/su12031112

Østhagen A (2020) Maritime boundary disputes: what are they and why do they matter? Mar Policy 120:104118. https://doi.org/10.1016/j.marpol.2020.104118

Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A (2016) Rayyan—a web and mobile app for Systematic Reviews. Syst Reviews. https://doi.org/10.1186/s13643-016-0384-4

Özcan Z, Willaarts B, Klessova S, Caucci S, Prista L, Adamos G, Laspidou C (2024) From nexus thinking to nexus implementation in South Europe and beyond: mutual learning between practitioners and policymakers. Sustain Nexus Forum. https://doi.org/10.1007/s00550-024-00538-w

Ozturk I (2015) Sustainability in the food-energy-water nexus: evidence from BRICS (Brazil, the Russian Federation, India, China, and South Africa) countries. Energy 93:999–1010. https://doi.org/10.1016/j.energy.2015.09.104

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, Moher D (2021) The Prisma 2020 statement: an updated guideline for reporting systematic reviews. BMJ. https://doi.org/10.1136/bmj.n71

Pahl-Wostl C (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob Environ Change 19(3):354–365. https://doi.org/10.1016/j.gloenvcha.2009.06.001

Pahl-Wostl C (2019) Governance of the water-energy-food security nexus: a multi-level coordination challenge. Environ Sci Policy 92:356–367. https://doi.org/10.1016/j.envsci.2017.07.017

Paná S, Marinelli MV, Bonansea M, Ferral A, Valente D, Valdez C, Petrosillo I (2024) The multiscale nexus among land use-land cover changes and water quality in the Suquía River basin, a semi-arid region of Argentina. Sci Rep. https://doi.org/10.1038/s41598-024-53604-0

Piguet E, Pecoud A, de Guchteneire P (2011) Migration and climate change: an overview. Refugee Surv Q 30(3):1–23. https://doi.org/10.1093/rsq/hdr006

Purwanto A, Sušnik J, Suryadi FX, de Fraiture C (2019) Using group model building to develop a causal loop mapping of the water-energy-food security nexus in Karawang regency, Indonesia. J Clean Prod 240:118170. https://doi.org/10.1016/j.jclepro.2019.118170

Purwanto A, Sušnik J, Suryadi FX, de Fraiture C (2021a) Quantitative simulation of the water-energy-food (WEF) security nexus in a local planning context in Indonesia. Sustain Prod Consum 25:198–216. https://doi.org/10.1016/j.spc.2020.08.009

Purwanto A, Sušnik J, Suryadi FX, de Fraiture C (2021b) Water-energy-food nexus: critical review, practical applications, and prospects for future research. Sustainability 13(4):1919. https://doi.org/10.3390/su13041919

Ripple WJ, Wolf C, Gregg JW, Rockström J, Newsome TM, Law BE, Marques L, Lenton TM, Xu C, Huq S, Simons L, King SD (2023) The 2023 state of the climate report: entering uncharted territory. Bioscience 73(12):841–850. https://doi.org/10.1093/biosci/biad080

Rogers P (2017) The triangle: energy, water & food nexus for sustainable security in the Arab Middle East. In *Water, Energy &Food Sustainability in the Middle East* (pp. 21–43). Springer. https://doi.org/10.1007/978-3-319-48920-9_2

Salmoral G, Zegarra E, Vázquez-Rowe I, González F, del Castillo L, Saravia GR, Graves A, Rey D, Knox JW (2020) Water-related challenges in nexus governance for sustainable development: insights from the city of Arequipa, Peru. Sci Total Environ 747:141114. https://doi.org/10.1016/j.scitotenv.2020.141114

Smajgl A (2021) Water, food, and energy nexus. In *Handbook of Catchment Management 2e* (pp. 93–124). https://doi.org/10.1002/9781119531241.ch5

Soleimanian E, Afshar A, Molajou A (2022) A review on water simulation models for the WEF nexus: development perspective. Environ Sci Pollut Res 29(53):79769–79785. https://doi.org/10.1007/s11356-022-19849-w

Sušnik J (2015) Economic metrics to estimate current and future resource use, with a focus on water withdrawals. Sustain Prod Consum 2:109–127. https://doi.org/10.1016/j.spc.2015.05.003

Torres Wong M (2019) Natural Resources, extraction and Indigenous rights in Latin America: Exploring the boundaries of environmental and state corporate crime in Bolivia, Peru and Mexico. Routledge, New York

Treemore-Spears LJ, Grove JM, Harris CK, Lemke LD, Miller CJ, Pothukuchi K, Zhang Y, Zhang YL (2016) A workshop on transitioning cities at the food-energy-water nexus. J Environ Stud Sci 6(1):90–103. https://doi.org/10.1007/s13412-016-0381-x

Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L, Hempel S, Akl EA, Chang C, McGowan J, Stewart L, Hartling L, Aldcroft A, Wilson MG, Garritty C, Straus SE (2018) Prisma extension for scoping reviews (PRISMA-SCR): checklist and explanation. Ann Intern Med 169(7):467–473. https://doi.org/10.7326/m18-0850

Tsutsumi K (2021) Depopulation, Aging, and Living Environments: Learning from Social Capital and Mountainous Areas in Japan. Springer, Singapore

Turner RA, Addison J, Arias A, Bergseth BJ, Marshall NA, Morrison TH, Tobin RC (2016) Trust, confidence, and equity affect the legitimacy of natural resource governance. Ecol Soc. https://doi.org/10.5751/es-08542-210318

Urbinatti AM, Benites-Lazaro LL, Carvalho CM, Giatti LL (2020) The conceptual basis of water-energy-food nexus governance: systematic literature review using network and discourse analysis. J Integr Environ Sci 17(2):21–43. https://doi.org/10.1080/1943815x.2020.1749086

van Zanten JA, van Tulder R (2020) Towards nexus-based governance: defining interactions between economic activities and Sustainable Development Goals (sdgs). Int J Sustain Dev World Ecol 28(3):210–226. https://doi.org/10.1080/13504509.2020.1768452

Vinca A, Parkinson S, Byers E, Burek P, Khan Z, Krey V, Diuana FA, Wang Y, Ilyas A, Köberle AC, Staffell I, Pfenninger S, Muhammad A, Rowe A, Schaeffer R, Rao ND, Wada Y, Djilali N, Riahi K (2020) The Nexus Solutions Tool (NEST) v1.0: an open platform for optimizing multi-scale energy–water–land system transformations. Geosci Model Dev 13(3):1095–1121. https://doi.org/10.5194/gmd-13-1095-2020

Vinca A, Riahi K, Rowe A, Djilali N (2021) Climate land energy water nexus models reviewed across scales: progress, gaps and best accessibility practices. Front Environ Sci 9:691523. https://doi.org/10.5194/egusphere-egu21-15989

Wada Y, Vinca A, Parkinson S, Willaarts BA, Magnuszewski P, Mochizuki J, Mayor B, Wang Y, Burek P, Byers E, Riahi K, Krey V, Langan S, van Dijk M, Grey D, Hillers A, Novak R, Mukherjee A, Bhattacharya A, Tong J (2019) Co-designing Indus water-energy-land futures. One Earth 1(2):185–194. https://doi.org/10.1016/j.oneear.2019.10.006

Warner K, Hamza M, Oliver-Smith A, Renaud F, Julca A (2009) Climate change, environmental degradation and migration. Nat Hazards 55(3):689–715. https://doi.org/10.1007/s11069-009-9419-7

Wegenast T, Schneider G (2017) Ownership matters: natural resources property rights and social conflict in Sub-Saharan Africa. Polit Geogr 61:110–122. https://doi.org/10.1016/j.polgeo.2017.07.007

Wiegleb V, Bruns A (2018) What is driving the water-energy-food nexus? discourses, knowledge, and politics of an emerging resource governance concept. Front Environ Sci. https://doi.org/10.3389/fenvs.2018.00128

Wilbanks, T. J. (2015). Putting "place" in a multiscale context: Perspectives from the Sustainability Sciences. Environmental Science & Policy, 53, 70–79 https://doi.org/10.1016/j.envsci.2015.04.009

Wolde Z, Wei W, Ketema H, Yirsaw E, Temesegn H (2021) Indicators of land, water, Energy and food (LWEF) Nexus Resource Drivers: a perspective on environmental degradation in the Gidabo watershed, southern Ethiopia. Int J Environ Res Public Health 18(10):5181. https://doi.org/10.3390/ijerph18105181

Yadav A, Singh S (2024) Environment and development: Balancing progress, preserving the planet and fostering collaboration for a sustainable future. Adv Asian Human-Environ Res. https://doi.org/10.1007/978-3-031-51696-2_12

Yanou MP, Ros-Tonen MAF, Reed J, Moombe K, Sunderland T (2023) Integrating local and scientific knowledge: the need for decolonising knowledge for conservation and natural resource management. Heliyon. https://doi.org/10.1016/j.heliyon.2023.e21785

Zaitchik BF, Bazzana D, Gebreyes M, Simane B, Siddiqui S, Gilioli G, Mueller-Mahn D (2022) Multi-scale challenges in the food–energy–water nexus. Sustain Dev Goals Ser. https://doi.org/10.1007/978-3-031-01336-2_7

Zare M, Mohammadi-Ivatloo B, Abapour M, Asadi S, Mohammadi G (2020) The necessity of a food–energy–water nexus approach for Lake Urmia Basin under the risks of climate change and environment degradation. Food-Energy-Water Nexus Resil Sustain Dev. https://doi.org/10.1007/978-3-030-40052-1_9

Zhang C, Chen X, Li Y, Ding W, Fu G (2018) Water-energy-food nexus: concepts, questions and methodologies. J Clean Prod 195:625–639. https://doi.org/10.1016/j.jclepro.2018.05.194

Zhang P, Zhang L, Chang Y, Xu M, Hao Y, Liang S, Liu G, Yang Z, Wang C (2019a) Food-energy-water (few) nexus for urban sustainability: a comprehensive review. Resour Conserv Recycl 142:215–224. https://doi.org/10.1016/j.resconrec.2018.11.018

Zhang P, Zhang L, Hao Y, Liang S, Liu G, Xiong X, Yang M, Tang W (2019b) Understanding the tele-coupling mechanism of urban food-energy-water nexus: critical sources, nodes, and supply chains. J Clean Prod 235:297–307. https://doi.org/10.1016/j.jclepro.2019.06.232

Zhang YF, Li YP, Huang GH, Ma Y (2021) A copula-based stochastic fractional programming method for optimizing water-food-energy nexus system under uncertainty in the Aral Sea Basin. J Clean Prod 292:126037. https://doi.org/10.1016/j.jclepro.2021.126037

Zhong H, Feng K, Sun L, Tian Z, Fischer G, Cheng L, Munoz Castillo R (2021) Water-land tradeoffs to meet future demands for sugar crops in Latin America and the Caribbean: a bio-physical and socio-economic nexus perspective. Resour Conserv Recycl 169:105510. https://doi.org/10.1016/j.resconrec.2021.105510

Ziv G, Watson E, Young D, Howard DC, Larcom ST, Tanentzap AJ (2018) The potential impact of Brexit on the energy, water and food nexus in the UK: a fuzzy cognitive mapping approach. Appl Energy 210:487–498. https://doi.org/10.1016/j.apenergy.2017.08.033