Earth System Governance 12 (2022) 100143

Contents lists available at ScienceDirect

Earth System Governance

journal homepage: www.sciencedirect.com/journal/earth-system-governance

The food water energy nexus in an urban context: Connecting theory and practice for nexus governance

Mari R. Tye [a,*], Olga V. Wilhelmi [a], Andrea L. Pierce [b], Saloni Sharma [b], Iuliana Nichersu [c], Michał Wróblewski [d], Wojciech Goszczyński [d], Jochen Wendel [e], Pia Laborgne [e], Monika Heyder [e], Iulian Nichersu [c]

[a] National Center for Atmospheric Research, Boulder, CO, USA
[b] Biden School of Public Policy & Administration, University of Delaware, USA
[c] Danube Delta National Institute for Research and Development, Tulcea, Romania
[d] Nicolaus Copernicus University, Toruń, Poland
[e] European Institute for Energy Research (EIFER), Karlsruhe, Germany

ARTICLE INFO

Keywords:
Food-water-energy nexus
Urban scale
Citizen science
Governance approach

ABSTRACT

The growing body of literature on the Food-Water-Energy (FWE) nexus during the last decade covers a variety of disciplinary perspectives and spatial scales. However, to date the urban FWE nexus has received less attention. In this paper, we review the FWE nexus literature with the focus on urban scale and identify gaps in the scholarly knowledge base with regard to practical applications for the FWE nexus governance in cities. Our findings suggest that there is still a mismatch between theoretical nexus governance and community perceptions. Successful governance is an iterative process, necessitating stakeholder input, reflection and response. While research developing the body of urban FWE governance knowledge has increased rapidly, reflection on those results to unpack the nexus complexity and support different governance actors is still limited.

We discuss an approach for making the FWE nexus connections more visible and practical by focusing on the urban governance actors and illustrating the intersecting interests and concerns of different actors within the food, water, and energy systems. Mapping the urban governance actors to the sub-elements of the FWE systems highlights common connections and overlapping interests, paving the road toward more integrated governance and participatory solutions. Identifying the tangible and intangible connections among governance actors also helps to reduce the ambiguity of the FWE nexus, and facilitates multi-stakeholder knowledge, data or resources sharing. The resultant approach aims to disaggregate the complexity of the FWE nexus and make its governance more attainable in cities.

1. Introduction

With more than half of the world's population presently living in urban areas (UN, 2012), much of the demand for food, water, and energy occurs in cities (Ramaswami et al., 2017). The inherent complexity of urban systems facing a number of social and environmental challenges creates a need for integrative management approaches. Over the past decade, urban sustainability and resilience have become key concepts in managing urban resources and addressing challenges associated with urbanization and global environmental change (Romero-Lankao et al., 2016). The urban Food-Water-Energy (FWE) nexus, first discussed at the World Economic Forum in 2008 (World Economic Forum, 2011), has been widely promoted as a mechanism for sustainable use of resources and a way for understanding complex socio-technical processes of urban metabolism and infrastructures (Graham, 2000). With recent research developing the trajectory of natural resources' governance from the state-national level to the supranational level by exploring the financialization of water, food and energy systems, and their connections to the global economy (Schmidt and Matthews, 2018).

Although the concept of FWE nexus thinking has been widely accepted, a consistent and explicit cognition of the FWE nexus is still lacking, and a sophisticated methodological framework that incorporates some level of modeling is urgently required at various scales (Zhang et al., 2019). In addition, FWE nexus studies employing

* Corresponding author.
E-mail address: maritye@ucar.edu (M.R. Tye).

https://doi.org/10.1016/j.esg.2022.100143
Received 8 May 2020; Received in revised form 25 March 2022; Accepted 26 April 2022
Available online 13 May 2022

bottom-up approaches are still poorly represented in the literature. Attention is, instead, mainly focused on the technical-administrative dimension (Weitz et al., 2017). Endo et al. (2020) highlight that studies crossing disciplinary boundaries and approaches are still very few. Given the abstract nature of the FWE nexus, there is still a lack of research linking the social perception of systems to the functioning of systems in local conditions (Portney et al., 2018). Urbinatti et al. (2020a) furthermore identified that the concept of FWE nexus Governance is underdeveloped in the literature, and is dominated by water governance issues even though the Nexus approach is aimed at removing that singular focus. However the development of a generalizable framework for FWE nexus implementation that can be adopted within and across different geographies is an outstanding challenge (Endo et al., 2020).

Recent funding opportunities have spurred the research community to address outstanding gaps within the Nexus knowledge landscape and particularly to build the corpus of knowledge relating community engagement to FWE nexus activities (e.g. Greer et al., 2020; Jones and White, 2021; Kliskey et al., 2021; Kropf et al., 2021; Melloni et al., 2020; Wahl et al., 2021). Thus an incremental step has been made on the road from incorporating lay knowledge into socio-technical solutions, but this information has not yet been translated into a deeper understanding of the "why" (Purwanto et al., 2021). The earlier lack of attention to the urban FWE nexus shifted during 2019–2021 to contribute at least one third of the new literature in that time (e.g. Jones and White, 2021; Wahl et al., 2021; Wolde et al., 2020).

In this paper, we review the literature on the urban FWE nexus with the goal of understanding how existing research covers urban applications and the gaps that still exist. In particular, we reflect on where recent empirical research can be incorporated into the governance of

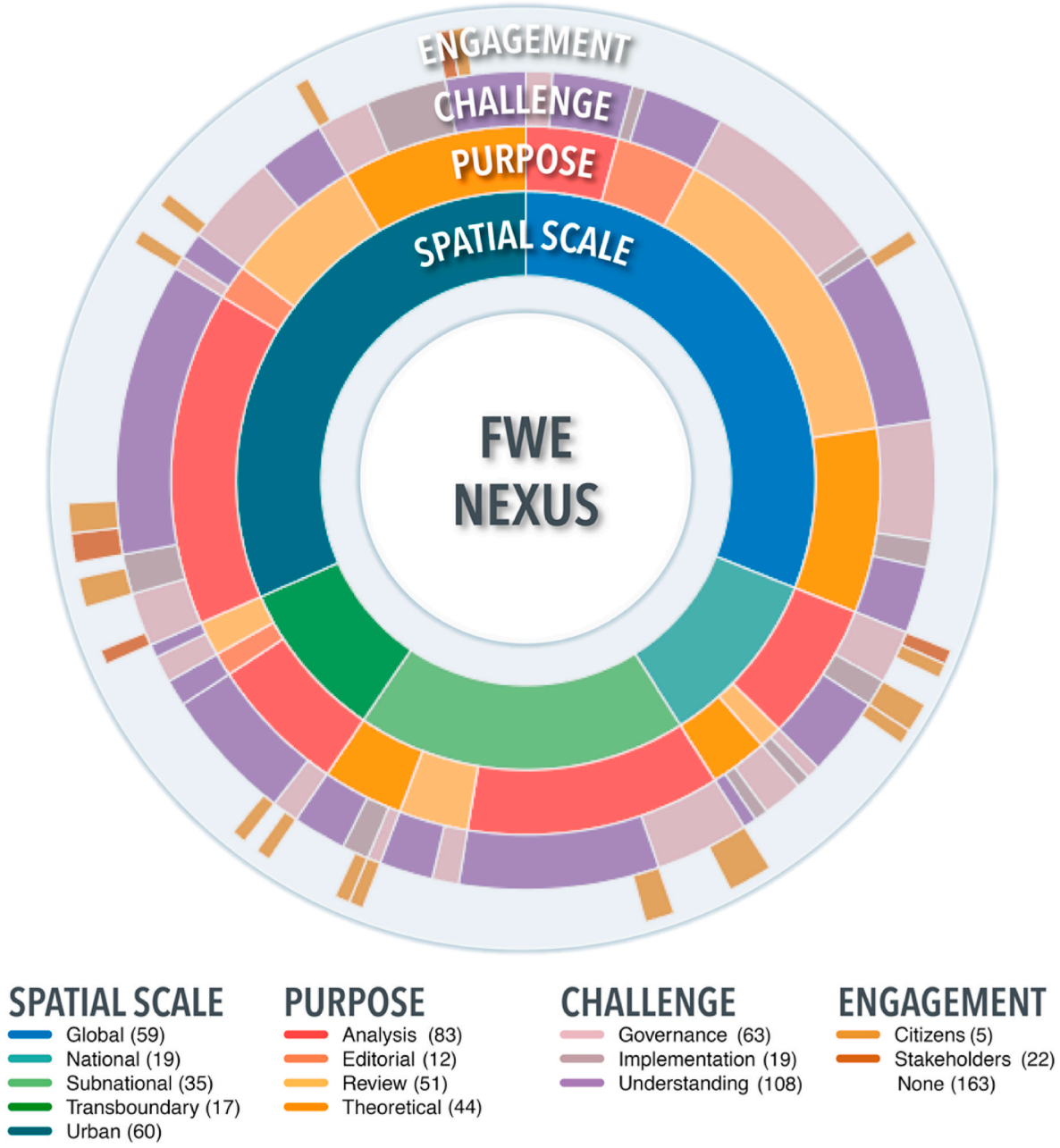

Fig. 1. Categorization of the literature addressing the FWE nexus, partitioned by the spatial scale of the research, overall purpose or scope, the application or challenge of the study, and whether members external to the research team were included. Numbers in parentheses correspond to the number of articles across all categories, with a total of 190 for each category.

local FWE nexus challenges through the use of local level community engagement and the incorporation of citizen science based methods. Based on this review, we propose an approach for making the connections among FWE systems more visible and the incorporation of stakeholders' knowledge, including that of available data, decision-making constraints and local challenges more transparent. The resultant approach aims to disaggregate the complexity of the FWE nexus and make its governance more attainable at the urban scale.

2. Literature selection

2.1. Methodology

The following literature review is based on a search of the Web of Science database, which used the keywords "Food OR Energy OR Water AND (Nexus OR System)" and focused on literature reviews and peer-reviewed literature published between 2015 and 2021. This period was selected to avoid duplication of effort, as several recent review articles cover the literature up to 2015 in considerable depth. Notable articles mentioned within the earlier reviews (e.g. Albrecht et al., 2018) and most closely aligned with objectives of our study (e.g. Bazilian et al., 2011; Bizikova et al., 2013; Bogardi et al., 2012; Burkhard et al., 2012a; Codoban and Kennedy, 2008; Hellegers et al., 2008; Sahely et al., 2003; Willemen et al., 2010), were also added to our analysis, yielding a total sample of 238 research articles.

Out of the total of 238 research articles, 190 covered the full Nexus of food, energy and water and are the basis of Fig. 1. This represents a slight advance from Endo et al. (2017)'s assessment of the state of research where around 50% of FWE nexus research covered the full spectrum. Recent research has demonstrated a greater effort to understand the interdependencies of each component across the spectrum of the FWE nexus (Parsa et al., 2021), often by focusing on a central challenge (e.g. Jones and White, 2021). However, the complexity of the challenges and the integration of diverse needs, data sources and governance boundaries have resulted in varying degrees of success (Dalla Fontana et al., 2021).

We categorized the literature to understand the intersection of the FWE Nexus with different aspects of research, and whether knowledge gained at some spatial scales can inform others. For instance, the trajectory from theoretical toward practical can be estimated from the proportions of research identified by its purpose. The flow of research might by illustrated as moving from Theoretical, through syntheses of the ideas in Reviews and Editorials, to an analytical understanding of how FWE elements interact together, feeding back into Theory. Previous research has demonstrated that the evolution along this path is further advanced for the larger spatial scales that it is for the urban FWE Nexus (Purwanto et al., 2021). This categorization was informative, rather than reducing the scope of the literature.

Our primary interest lay in determining how the FWE Nexus is either governed or implemented at other scales, to translate that research to the urban landscape. Thus we classified literature by the nature of the challenge they addressed, retaining 171 articles across all spatial scales. Finally, we examined whether the research had incorporated some level of stakeholder engagement. Twenty seven of the remaining articles represented research that had some level of stakeholder engagement; of which the majority (11) were analyses aimed at understanding (11) or governing (11) the Nexus, and only 5 papers described implementations of the FWE nexus. These five form the basis of our estimate of research gaps presented in Section 3, as the remaining questions and articles have been thoroughly reviewed elsewhere (e.g. Albrecht et al., 20187; Parsa et al., 2021; Pierce et al., 2021; Purwanto et al., 2021; Urbinatti et al., 2020a,b).

2.2. Filtering the relevant literature

Fig. 1 illustrates the breakdown of reviewed literature (190 articles) by spatial scale, overall purpose of the study, the main FWE nexus challenge addressed by the researchers, and whether any form of stakeholder engagement or citizen science were part of the study. These categories were informed by Albrecht et al. (2018), Newell et al. (2019) and Dai et al. (2018) and are described below. At first glance, the main message of Fig. 1 is the heterogeneity of the literature; the next most salient point is that the majority of research at all spatial scales (except global) is analytical (83 of 190 articles). Finally, the gap in implementing social science methods to connect theory to practice is evidenced by the sparse outer circle (27 articles of the 190 total).

Spatial scale: **Urban** scale includes FWE nexus studies conducted at a city or community level; **subnational** scale studies encompass counties or states; **national** represents FWE projects at a country scale; **transboundary** scale includes multiple countries or large watersheds spanning across national boundaries, and **global** scale explores FWE nexus connections around the world. While the urban scale comprises a large portion of Fig. 1, this reflects the scale of our interest rather than the dominance of any scale in recent research.

Purpose: We divided the overall purpose of the articles into **editorial** overviews or introductions to special issues, **reviews** of extant literature, **theoretical** articles that focus on the concepts of the FWE nexus, and **analytical** studies based on empirical data or modeling approaches.

Challenge: This category represents different research challenges addressed by the authors. These include studies focused on **understanding** of the physical linkages between elements in the FWE systems, studies that focused on the FWE **governance** and are geared specifically to inform institutional policies or decisions, and studies that explore how to apply the FWE concepts through practical **implementation** and specific interventions.

Engagement: Here, we selected papers that included the stakeholder engagement process. We highlighted papers that involved **citizens,** study participants who did not represent a larger organization and contributed to data collections via surveys or Urban Living Labs. **Stakeholders** generally had active involvement through the course of the study by sponsoring research (e.g., the UN Food and Agriculture Organization; FAO, 2018), co-producing knowledge in workshops or contributing to the design of the research.

3. Literature review

3.1. Research landscape

Such is the interest in the FWE nexus, that our literature search revealed 37 review papers, with 25 published during the period 2019–2021, and at least 15 different journal special issues (Abraham, 2018; Allan et al., 2015; Azapagic, 2015; Caputo et al., 2021; Clarens and Peters, 2016; Dalla Fontana et al., 2021; Endo et al., 2020; Grady et al., 2019; Itayi et al., 2021; Kapucu et al., 2021; Keskinen and Varis, 2016; Liu et al., 2018; Mohtar and Daher, 2019; Monstadt and Coutard, 2019; Pahl-Wostl et al., 2018; Parsa et al., 2021; Purwanto et al., 2021; Taherzadeh et al., 2018; Taniguchi et al., 2017; Teisl et al., 2017; Urbinatti et al., 2020a,b; van Gevelt, 2020; Vinca et al., 2021; Wahl et al., 2021). A common observation among the review papers is that very few studies manage to capture the full spectrum of FWE systems (Albrecht et al., 2018; Al Saidi et al., 2017; Endo et al., 2015; Newell et al., 2019; Shannak et al., 2018). Wichelns (2017) suggests that the beauty of the FWE nexus question lies in its very ambiguity, where the lack of consensus around themes and approaches enables each researcher to adopt their own interpretation and central focus. In contrast Al Saidi et al. (2017) find that this ambiguity in the FWE nexus arises from the lack of an overarching theory or governance framework, which limits its adoption into decision-making bureaucracy. The ambiguity is also apparent from the diverse foci of each review article, including methods and tools (Albrecht et al., 2018; Al Saidi et al., 2017; Del Borghi et al., 2020; Endo et al., 2017, 2020; Kaddoura and El Khatib, 2017; Mannan et al., 2018; Namany et al., 2019), the

theoretical/historical evolution from other disciplines (Fan et al., 2019; Newell et al., 2019; Roidt and Avellán, 2019), legislative frameworks (Kaddoura and El Khatib, 2017; Kapucu et al., 2021; Mpandeli et al., 2018; van Gevelt, 2020) and urban applications (Covarrubias, 2019; Fan et al., 2019; Kliskey et al., 2021; Mirabella et al., 2019; Zhang et al., 2019).

The burgeoning literature on the FWE nexus during the last decade or so covers a variety of different disciplinary perspectives and conceptual models. Similar to the evolution of resilience theory (e.g. Holling, 1973), FWE nexus research has evolved from ecological and environmental disciplines addressing increasing resource scarcity, through sector-specific analyses minimizing tradeoffs to achieve efficient consumption, to the question of integrated governance (Al-Saidi and Elagib, 2017). Newell et al.'s (2019) six "scholarly communities" (Ecology, Food, Energy-Biofuels, Energy-Food, Food-Energy-Water, Urban Food-Energy-Water) illustrates this transition of FWE nexus analyses from the ecological domain to the more recent interest in urban problems. Motivated by Keskinen and Varis's (2016) observation that the FWE nexus can serve multiple roles, from a motivator for discourse to a method for analysis, Albrecht et al. (2018) also found that six major disciplines (Environmental Sciences, Social Sciences, Energy, Agricultural and Biological Sciences, Engineering, Biochemistry) dominated the development of FWE nexus methods and tools. While more recent research still has a substantial presence in the environmental and sustainability literature, the number of publications in policy oriented journals has increased (e.g. Kapucu et al., 2021; Kropf et al., 2021; Yan and Roggema, 2019).

As shown in Fig. 1, there is a tendency for analytical papers to occur at the smaller spatial scales, such as urban, and theoretical and reviews to focus on larger spatial scales (Dai et al., 2018). A similar tendency occurs with the analytical methods employed. That is, methods such as scenario analysis or footprinting are more prevalent at the larger scales, and methods such as life cycle assessment or input-output analysis are more frequently employed at the smaller spatial scales (Albrecht et al., 2018; Kaddoura and El Khatib, 2017; Namany et al., 2019; Newell et al., 2019).

Recent literature has sought to fill some of the knowledge gaps that arise when considering challenges experienced by urban communities, and how implementation of the FWE nexus might resolve those challenges (Wahl et al., 2021; Kliskey et al., 2021). Inevitably, incorporating the perspectives of local participants has raised as many new research questions as they have resolved. For instance, Kliskey et al. (2021) flag the importance of appropriate and inclusive language in engaging communities in addressing nexus challenges. However, the target of linking research to practice has remained elusive (Urbinatti et al., 2020a,b), with an outstanding need for interdisciplinary, integrated research that connects local social challenges to the constraints imposed by governance (Covarrubias, 2019; Dalla Fontana et al., 2021; Wahl et al., 2021).

3.2. Conceptualizing the nexus

Even when all sectors are considered in the analysis, many FWE nexus studies focus on the issues arising within one sector (i.e. an entry point) and establish connections to the other two. In general, the literature review reveals that the entry points and analysis methods for FWE nexus research change with respect to the scale of the study, as do the actors and their typical involvement (Albrecht et al., 2018; Artioli et al., 2017; Endo et al., 2015; Shannak et al., 2018). The historical importance of integrated water management plans has tended to focus research toward the water sector (Urbinatti et al., 2020a). Spatial scales of interest range from global (Bijl et al., 2018; D'Odorico et al., 2018) to transboundary or regional watershed (Daccache et al., 2014; Guillaume et al., 2015; Karabulut et al., 2016; Keskinen and Varis, 2016) and individual countries (Stein et al., 2018; Talozi et al., 2015; Willemen et al., 2010), to the city (White et al., 2017), community (Chance et al., 2018; Gondhalekar and Ramsauer, 2017), or even household (Hussien et al., 2018) scale. Each scale presents its own advantages, data availability and drawbacks or assumptions that are made. In common with other reviewers, we find that a limited number of studies manage to capture the full spectrum of food, energy and water, and that governance occurs at a national or regional level, while implementation is more localized (Shannak et al., 2018; Huntington et al., 2021; Abulibdeh and Zaidan, 2020). We also find that at global and transboundary scales, studies are often funded by national or international organizations interested in the possible socio-economic ramifications of policy changes. Furthermore, the greater the spatial scale, the more likely it is that the FWE nexus is considered as a system rather than as the tangential outcomes from one sector (e.g. carbon mitigation in the energy sector) on the other two (Keskinen and Varis, 2016).

The boundaries of decision-making and motivating concern for the urban FWE nexus differ at each scale (Mohtar and Daher, 2019), with water being the focus at the largest scales – usually arising from transboundary river basin management (e.g. Bijl et al., 2018; Roidt and Avellán, 2019). Conversely, at the community or household scale, food is the primary motivating concern (Pahl-Wostl, 2019). In particular, food security is often considered at the smallest spatial scale compared with water and energy challenges – possibly because this is where individuals have the greatest autonomy (Kharanagh et al., 2020) and food is more tangible compared to water or energy. Mapping the interdependence and interfaces across governance systems, organizations or institutions, and space reveals a similar temporal scale of decision-making and operations with time proportional to the complexity of the FWE nexus and network (Monstadt and Coutard, 2019; Schulterbrandt Gragg et al., 2018) that is rarely considered in sufficient detail within the research (Newell et al., 2019; Mohtar and Daher, 2019).

When governance of the FWE nexus stems from a series of policy oriented adaptation actions originating in a specific sector, as often occurs, conflicting or counter-productive actions are often the result (Rasul and Sharma, 2016). However, the majority of studies are theoretical in nature, using empirical data to identify how the FWE nexus operates and the impacts of one sector on the other two. Yet, at the city or community scale a study that links the theory to empirical research would possibly assist decision-makers in understanding the sector interactions and policy overlaps (e.g. Artioli et al., 2017; Purwanto et al., 2019).

Defining "powerful" organizations and institutions as those with the greatest interest in the FWE nexus, with inherent complexity and a higher degree of decision-making power (Kharanagh et al., 2020). Thus, the most powerful organizations and institutions tend to be governmental or public entities, shown on the x-axis in Fig. 2. The temporal scale is tied to this: short-term decisions and activities (weekly to annual) are far more likely to be made by individuals and small groups (e.g. Gondhalekar and Ramsauer, 2017; Dai et al., 2018), businesses operate over one to multiple years (e.g. Sharmina et al., 2016), and government operations tend toward decadal timescales (e.g. Guillaume et al., 2015; Hoolohan et al., 2018; Harwood, 2018). This suggests a correlation between short-term decisions and the spatial scale of decisions (Frantzeskaki and Kabisch, 2016) or social and economic activity (Artioli et al., 2017; Covarrubias, 2019) in addition to the degree of power exerted by specific actors in the policy cycle and especially the agenda setting as well as the decision-making process.

Synthesizing the literature on spatial, temporal and power scales in Fig. 2 makes it more apparent that it is rare that a fully tripartite FWE nexus study occurs at the smallest scales. Fig. 2 illustrates the common themes that arise for different spatial scales and participants, i.e., there is a greater interest in FWE connections and their governance structures at larger spatial scales. This does not imply that no systems-wide FWE nexus studies occur below the global level, only the literature revealed very few studies at the urban/metropolitan scale that considered the full FWE nexus (Artioli et al., 2017; Urbinatti et al., 2020a,b; Kapucu et al.,

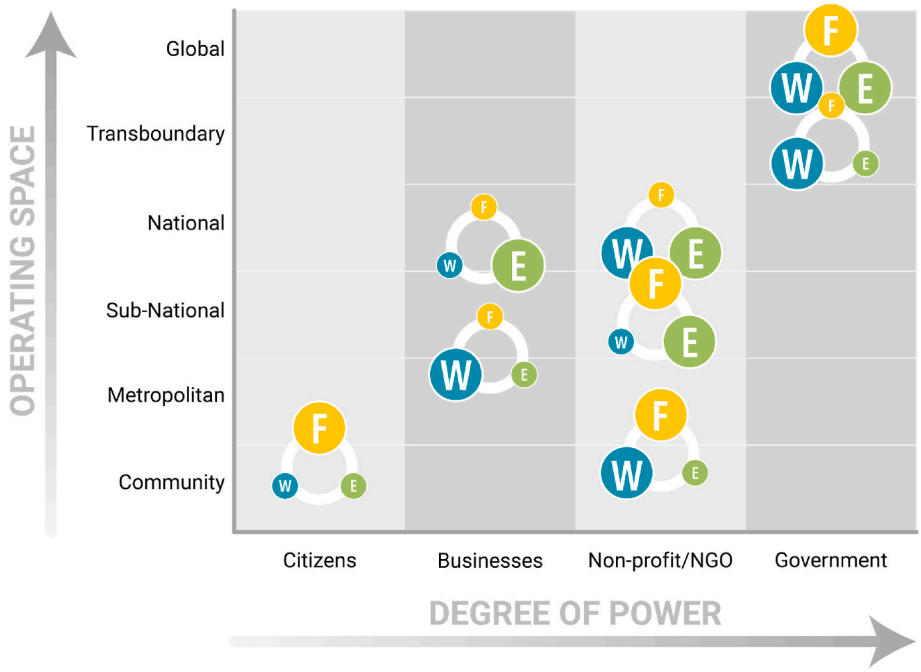

Fig. 2. Illustration of the dominant element in the FWE nexus with respect to different actors encountered within the literature (x-axis) and the spatial scale at which the literature focuses (y-axis). Circles represent different Nexus elements: Food (yellow), Water (blue), Energy (green), with larger circles indicating a dominating Nexus element.

2021). There is little published literature addressing FWE local governance, and associated FWE strategies or policies, or community participation (Nichersu et al., 2020; van Gevelt, 2020).

3.3. *FWE nexus governance*

Although many scholars acknowledge the importance of FWE nexus governance, there continues to be a gap in the empirical analysis of the roles of different organizations in managing, governing or interacting with the FWE nexus (Newell et al., 2019; Urbinatti et al., 2020a; Jones and White 2021; Kurian and Ardakanian, 2015). Broadly speaking, governance encompasses the processes of managing society for collective benefit. While many people associate governance with acts of official government entities (i.e., public policy), the broader literature acknowledges that many individual actors and institutions – public, private, and non-profit – may be involved in governance through formal or informal linkages (Hagemann and Kirschke, 2017; Stoker, 1998). The beyond-government framing of governance is particularly important for urban FWE nexus studies, given that the important actors in FWE systems may not reside in government. Government must work collaboratively with others, particularly local actors, to achieve collective goals such as sustainability and resilience.

A recurrent theme in the literature on FWE nexus governance is the fragmentation of policies between the different sectors (e.g. Weitz et al., 2017), and the absence of effective two-way collaborations at different levels of governance to integrate the policies (Daher et al., 2019; Urbinatti et al., 2020a). Such collaborations would ideally utilize more participatory methods, incorporate traditional knowledge approaches, and emphasize the importance of local stakeholder involvement and urban institutional connections (Daher et al., 2019; Urbinatti et al., 2020a; White et al., 2017). For instance, analysis of urban FWE nexus governance needs to review policy coherence and integration horizontally across the three sectors in one place, and vertically between governance institutions at the differing geographic scales that affect the urban landscape (Weitz et al., 2017; Stein et al., 2018; Urbinatti et al., 2020b). As noted earlier, a disconnect persists between the geographies at which the three sectors manifest (i.e., watersheds) and the levels at which urban society is governed (i.e., cities, counties, states, nations).

As an interesting aside, there is often a mismatch between the perceived leading Nexus concern, and the issue around which stakeholders eventually coalesce to coordinate the FWE nexus. For instance White et al. (2017) noted that water scarcity was the primary concern in Phoenix (USA), yet the majority of the sector specific stakeholders converged around an agricultural issue to pursue incremental policy changes or encourage behavior change. By focusing on one of around 24 core "themes" such as environmental governance or climate change (Urbinatti et al., 2020a), the collective problem and modes of effective governance may be illuminated (e.g. Stein et al., 2018; Huckleberry and Potts, 2019; Romero-Lankao et al., 2017; Pahl-Wostl, 2019).

In essence, there has been substantial assessment of where attention needs to focus to improve the transfer of theoretical governance to practice, and identifying the instruments or activities to achieve changes, but less focus on the efficacy of these suggestions. Bridging organizations whose functions cut across sectors have been identified as an important mechanism to traverse multi-level governance networks and horizontal interactions (Stein et al., 2018). Yet there are often external geopolitical considerations or fixed institutional hierarchies that can constrain governance arrangements or pose an additional challenge to cross-sector collaborations (Stein et al., 2018; Huckleberry and Potts, 2019). Huckleberry and Potts (2019) argue that governance arrangements must be considered centrally if we are to meet FWE security challenges in the future.

The concept of FWE security has not been well-defined or operationalized, despite serving as an important motivating factor for Nexus studies (Romero-Lankao et al., 2017). Pahl-Wostl (2019) argues that polycentric, multi-level governance arrangements are a requisite component of achieving FWE security and sustaining lives and livelihoods, through an appropriate balance of trade-offs and synergies between the three systems. However, governance instruments for managing interactions within such arrangements tend to be lacking. Appropriate instruments depend on the type of interaction between actors and FWE sectors, which again depends on the empirical context and can only be identified through careful systemic analysis (Pahl-Wostl, 2019). The implementation then depends on developing

appropriate institutional settings and rules to enable effective interactions, as argued by institutional scholars (Ostrom et al., 2014).

The FWE nexus governance literature generally employs either case study analyses of single, highly contextualized cases, or abstract, macro-scale analyses that lead to only general governance suggestions such as improving stakeholder participation (Artioli et al., 2017; Hagemann and Kirschke, 2017). Comparative analyses that would help build our knowledge of governance structures, instruments, or strategies that might improve FWE nexus management in multiple settings that face similar types of problems are rare to date (Kapucu et al., 2021; Urbinatti et al., 2020a). Such approaches are particularly needed due to the lack of empirical analysis of FWE nexus governance in urban settings (Artioli et al., 2017). Urbanization and economic development drive demand for food, water, and energy, and can undercut FWE security in cities. Power dynamics within cities raise concern about equity in access to resources and in governance processes (Romero-Lankao et al., 2017). Pursuit of managerial efficiency underlies many FWE nexus conversations, potentially constraining policy discussions to market-based solutions and favoring private sector actors. Especially within the urban context, "directions for further research arise around the question of which actors have authority and capacity for integrated [Nexus] management, and how they conceive the problems of water, food and energy sectors" (Artioli et al., 2017, p. 221).

The level of interest and support for FWE nexus related policy instruments depends not only on the spatial scale of interest (e.g. Williams et al., 2019), but also on the defining purpose of the FWE nexus (Bullock and Bowman, 2018), with greatest interest amongst those who are concerned with wasted resources (Hannibal and Portney, 2019). Interest may also be hampered by researchers missing the opportunity to connect the Nexus within the influence of social norms and policy uptake (Covarrubias, 2019). Given the multiple geographical scales involved in the urban FWE nexus (Williams et al., 2019), stakeholders may appreciate the concept of FWE nexus integration but they often also perceive considerable difficulties in its implementation (White et al., 2017; Jones and White, 2021). Support for FWE nexus issues at the urban scale appears to be highest for food-related concerns, particularly when the far-reaching consequences are made more apparent (Bullock and Bowman, 2018; Caputo et al., 2021; Greer et al., 2020; Gondhalekar and Ramsauer, 2017; Wolde et al., 2020).

3.4. *Engagement at the urban scale*

As noted above, food is often the driving focus for FWE nexus research at the urban scale, with a particular emphasis on resource management or sustainability (Al-Saidi and Elagib, 2017; Dai et al., 2018). The literature often promises a mechanism to improve integrated FWE nexus governance, but equally often fails to deliver the specifics as definitions of the FWE nexus and its governance remain unclear (Allan et al., 2015; Zhang et al., 2019). Instead, the focus is on quantifying and understanding the physical manifestation of the FWE nexus (Albrecht et al., 2018). Quantification of the urban Nexus takes several forms, all of which are more effective when they incorporate participatory methods (Albrecht et al., 2018; Wahl et al., 2021). While Nexus quantification with scientific data analysis can play a role in determining the central issues with which cities or communities grapple (Soomro et al., 2019), there is still a considerable need to determine who the key players in the FWE nexus are (Artioli et al., 2017; Schulterbrandt Gragg et al., 2018; Zimmerman et al., 2018). As the data used in the majority of these studies are publicly available spatial or non-spatial datasets, it is unsurprising that there remains a pressing need to identify how to operationalize the FWE nexus (Bizikova et al., 2013) and to link from theoretical and empirical analyses into a governable Nexus or an implementable set of practical policies (Artioli et al., 2017; Sperling and Berke, 2017).

Lawford (2019) draws on the findings of several workshops, revealing that the absence of readily accessible and comparable data and meta-data, co-designed with decision-makers is one of the greatest barriers to effective FWE nexus implementation in planning and decision-making. Similarly, Bizikova (2019) found that collaborative teams built solely from subject-matter experts, rather than including those with a mandate to effect change, were unsuccessful in their attempts to link analysis with practice. Qualitative methods were favored as a means of engaging more fully with key stakeholders, when they can be identified. Furthermore, Bizikova (2019) confirms that the unequal balance between FWE nexus elements, is often driven by pressing local problems and that this might be rectified by including less represented sectors. We also note that FWE nexus studies conducted at the urban scale are largely represented by North American and Western European cities, revealing a large gap in our understanding of the urban FEW Nexus and how it may be implemented in developing countries.

Even with the recent interest in participatory methods and FWE nexus integration, the literature revealed few instances of interactive and participatory research. One of the key attributes of successful FWE research projects is to involve stakeholders in framing the research, and identifying a common vision and questions of interest (Bizikova, 2019; Frantzeskaki and Kabisch, 2016; Dalla Fontana et al., 2021). Co-developing knowledge, tools and policy recommendations, of necessity, requires an inclusive and iterative approach starting from a common foundation and ensuring that all voices are represented (White et al., 2017; Melloni et al., 2020; Kliskey et al., 2021). Thus, addressing complex urban FWE nexus challenges depends not only on a coordinated stakeholder engagement plan, but also on a fully interdisciplinary perspective (Mohtar and Daher, 2019; Wahl et al., 2021) that operates at multiple scales and draws on local perspectives (Feng et al., 2019; Liang et al., 2019; Kropf et al., 2021). In common with Sperling and Berke (2017), we find that engagement of those most affected by urban governance decisions (i.e., the city residents) is a rare focus of research. Rather, we found that most stakeholder interactions were with other researchers or those working with policy makers, and very few were with business, industry, media or civil society (Endo et al., 2017).

Stakeholders in the literature on urban FWE nexus have involvement in the research somewhere on a scale between passive and active participation. Fully passive stakeholders are the subjects of pre-defined hypotheses with no opportunity for additional interaction with the research, for instance responding to surveys or questionnaires (Endo et al., 2015; Hussien et al., 2018; Song et al., 2019). At the next level, while the research questions are already established, participants have greater opportunity to inject their perspectives and knowledge through interviews or focus groups (Chance et al., 2018; Romero-Lankao and Norton, 2018; Schulterbrandt Gragg et al., 2018; White et al., 2017). The subset of the urban FWE literature that describes fully interactive stakeholder engagement and identifies governance related issues amounted to 6 of the full complement of papers that we reviewed. Even within this "active participation" group, there are varying degrees of involvement and inclusivity in the stakeholder groups. A new focus on gathering citizens' perspectives from "Living Laboratory" approaches (e.g. Kropf et al., 2021; Jones and White, 2021; Yan and Roggema, 2019; Melloni et al., 2020; Wolde et al., 2020; Wahl et al., 2021) has emerged recently. Yet a disconnect still exists between understanding how the FWE nexus is perceived at the local level and how it can be managed.

Several researchers have noted that the FWE nexus' intrinsic complexity of spatial scales, multiplicity of actors and perspectives necessitates a multi-layer analysis that is adaptable for each focal point or location (Cottee et al., 2016; Veldhuis et al., 2019). This approach also helps to compare different stakeholder perceptions and to identify where changes in governance or implementation could occur, or the responsibilities of different stakeholders (Halbe et al., 2015). In particular, decisions often take place at different spatial and temporal scales for different stakeholders, making it difficult to delineate the formal boundaries of the research and the Nexus stakeholder network (Mohtar and Daher, 2019).

Mohtar and Daher (2019) also emphasized a recurrent concern with

participatory research: that achieving the project goals is highly dependent on an iterative process, with collective participation toward synergistic goals. Greater interactions through cooperative stakeholder groups lead to enhanced communication across the FWE nexus elements (Daher et al., 2019), but only when those groups have been established with equal emphasis for organizations across the FWE nexus. Furthermore, those communications need to occur at frequencies that align with each stakeholders' decisions, rather than the longer timescales adopted by researchers (Daher et al., 2020). However, it is also difficult to engage the full spectrum of involved parties, forcing researchers to focus on a subset of potential stakeholders (Cottee et al., 2016). For instance, consumers are a vital part of the food supply chain, but of necessity Veldhuis et al. (2019) limited their stakeholder interactions to producers and distributors.

Framing the FWE nexus question appropriately was also regularly identified as a key opportunity to improve facilitation and collaboration between groups. Ecosystem services, for instance, are a valuable narrative device to facilitate discussions and central to the challenges experienced in many cities (Frantzeskaki and Kabisch, 2016). However, the most successful implementations allowed the framing to develop organically within the local community (e.g. Daher et al., 2019; Halbe et al., 2015; Laborgne et al., 2021). Stakeholder workshops and urban living laboratories (ULL) have been found by many to be successful in creating a collaborative environment that allows the group to identify key environmental problems, knowledge gaps or mismatches, and development of responsive strategies and to gain new knowledge and perspectives on the FWE nexus elements (e.g. Frantzeskaki and Kabisch, 2016; Daher et al., 2020; Jones and White, 2021; Wahl et al., 2021).

3.5. *Evolving and varying conceptualization of FWE nexus*

In the same way as the focus of FWE nexus research varies with the spatial scale of interest, the literature points to different frameworks for research being more common at particular spatial scales (Bizikova, 2019; Bijl et al., 2018). Endo et al. (2017) indicate that the concept and supporting activities vary depending on the social, economic and environmental goals of the region and sector. Given that each location and spatial scale has its own accompanying pressures, norms and management schemes (Guillaume et al., 2015), there is also a place for a dynamically varying framework (Smajgl et al., 2016). However, as Bazilian et al. (2011) highlighted, many challenges exist due to a lack of conceptual models, tools, and data sets that can supply information on FWE interactions within existing regulatory structures and cultures. This challenge of insufficient models, tools and data appears to have remained unresolved for the course of the decade (Fernandes Torres et al., 2019). Furthermore, the lack of a common approach makes it difficult to effectively compare the outcomes of different studies (Albrecht et al., 2018; Babaie et al., 2019; Cai et al., 2018; Crossman et al., 2013; Shannak et al., 2018).

Framing the FWE nexus appears to follow two overall approaches in the literature: either conceptual (theoretical) frameworks that lack guidance on the connection to empirical research, or analytical frameworks tied to a specific methodology but without theoretical backing. The nature of external participation is also tied to the selected framing. That is, theoretical frameworks are more likely to include individuals and organizations who fund, co-direct, or otherwise support the research (e.g. Bielicki et al., 2019; de Strasser et al., 2016; Howarth and Monasterolo, 2016; Lawford, 2019; Purwanto et al., 2019). These frameworks offer greater opportunities to include participatory scenario building (Johnson and Karlberg, 2017) and integrative science-stakeholder dialog (Mohtar and Daher, 2016) or integrated modeling (Bazilian et al., 2011). In contrast, analytical frameworks tend to draw on external participants as a source of data (e.g. Endo et al., 2015; Keskinen et al., 2015; Laspidou et al., 2019; Song et al., 2019; Spiegelberg et al., 2017; Stein et al., 2018; Ziv et al., 2018).

Theoretical frameworks present a mechanism to examine the interplay of resources and infrastructure with policies and social practices through a variety of FWE lenses. Tracing through the perspectives presented historically also highlights the shifts in FWE nexus thinking from environmental and resource foci (Newell et al., 2019) toward social and political science (Williams et al., 2019). For instance security perspectives (Beck and Villarroel-Walker, 2013; Bizikova et al., 2013; Bogardi et al., 2012; Burkhard et al., 2012b; Kremer and DeLiberty, 2011) and a focus on livelihoods (Biggs et al., 2015) motivated earlier frameworks. Governance (Artioli et al., 2017; Hagemann and Kirschke, 2017; Weitz et al., 2017), trade (Bijl et al., 2018) and resilient urban systems (Ramaswami et al., 2017; Romero-Lankao et al., 2017) are among other issues used to frame the FWE nexus. However, as noted above, few of these frameworks make FWE nexus interlinkages fully visible at the urban scale and use varied terminology for the same concepts (Gunda and Tidwell, 2019).

Analytical frameworks also present a trajectory from ecosystems led analyses (Codoban and Kennedy, 2008; Sahely et al., 2003), through environmental accounting (Al-Ansari et al., 2015; Boyer and Ramaswami, 2017; Villamayor-Tomas et al., 2015), into a more socio-driven agenda (Covarrubias, 2019; Romero-Lankao et al., 2018; Yung et al., 2019). The notable absence within the literature is, however, a framework that makes the theoretical FWE nexus linkages visible and understandable to stakeholders, and facilitates cooperation and knowledge exchange through an innovative, interdisciplinary approach (Biggs et al., 2015; Hagemann and Kirschke, 2017; Mohtar and Daher, 2016).

Recent literature has generated much needed empirical knowledge around the implementation of the FWE nexus at the urban scale. However, we find that there is still a mismatch between the theoretical constructs, local/community perceptions of the FWE nexus and the overall governance. As noted by Pierce et al. (2021) successful governance is an iterative process, necessitating stakeholder input, reflection upon the new knowledge, and re-engagement. In this paper, we reflect upon recent empirical knowledge and attempt to unpack the complexity in a way that will support different governance actors.

4. Connecting theory and practice for urban FWE nexus governance

Review of the FWE nexus literature revealed several challenges in connecting the theoretical nexus constructs to empirical research and practical applications. To make the urban FWE nexus construct more practical, the 'quality of life' framework, representing intersecting concerns, such as livelihoods, social equity, and resilience (Bizikova et al., 2013; Bizikova, 2019) can be applied. This theoretical construct can be extended to address the complex interlinkages presented by urban infrastructures, multi-level governance as well as knowledge and data sharing, by starting to breakdown the nexus into the individual relationships. Critically, identifying both the intrinsic stressors and processes, and the extrinsic controllers on the nexus highlights how each element interacts at different spatial and temporal scales (Shannak et al., 2018; Ramaswami et al., 2017). Furthermore, anchoring FWE nexus systems in real-life urban challenges and needs, such as quality of life or supply security of fundamental services, can increase social awareness and the ability to engage citizens in the FWE nexus governance.

Prior research highlighted that it is difficult to identify and integrate FWE nexus knowledge without a foundational examination of the individual sectors to facilitate data collection and stakeholder collaboration (Mohtar and Daher 2019). Disaggregating the nexus and each contributing sector into individual relationships, including their geographical domain, time-frame for decision-making and their purpose, can assist with developing a more streamlined nexus governance (Dalla Fontana et al., 2021). Identifying the roles of different actors in the FWE nexus (Newell et al., 2019; Urbinatti et al., 2020a; Jones and White, 2021; Kurian and Ardakanian, 2015) and examining "intersectionality" of FWE nexus system elements as well as "interactionality" of feedback loops within the systems (Kurian and Ardakanian, 2015, pp.

7–8; Parsa et al., 2021) can further facilitate the nexus governance. This requires understanding how different groups of stakeholders or governance actors interact with different elements of the food, water and energy systems, and where the potential for common connections, overlapping interests and shared knowledge, data or resources exist.

For this more detailed and practical conceptualization, we first outline relevant elements of the urban water, food and energy systems, such as generation, storage, distribution, processing and consumption. Second, we map different spheres of engagement with these systems' elements for different urban governance actors. Fig. 3 shows this actor-to-system element mapping for local government (Fig. 3a), the private sector (Fig. 3b), and the citizens (Fig. 3c) and highlights the specific elements of the water, food, and energy systems as likely spheres of engagement for different actors. For example, citizens have fewer points of interactions with the water and energy systems compared to the food system (as discussed in Section 3.2). Citizens typically act as consumers of water and energy, although they may participate in the energy production (e.g., using urban gardens to help with storm water management or helping generate energy through solar panels or biofuels). In contrast, citizens can engage in a variety of food system-related activities ranging from production (i.e., urban gardens) to processing and disposal.

Identifying how actors interact with each of the FWE systems' elements can help to create pathways or scenarios of the cross-system (i.e., Nexus) engagement. As illustrated in Fig. 3c, citizens may produce or purchase, prepare and consume food products, requiring the consumption of energy and water supplied by others. There is also a potential for citizens to be involved in generation of alternative, green energy through participation in the community energy projects, using solar or biofuel sources. Fig. 3a and b shows similar interactions, but from the perspective of the local government and local businesses. We note that this is a generalized representation, as some interactions such as distributing or providing access to food are not the direct responsibility of local government in certain locations, but are in others. Furthermore, how these interactions manifest may vary according to the activity, stakeholder and location. In particular, decisions often take place at

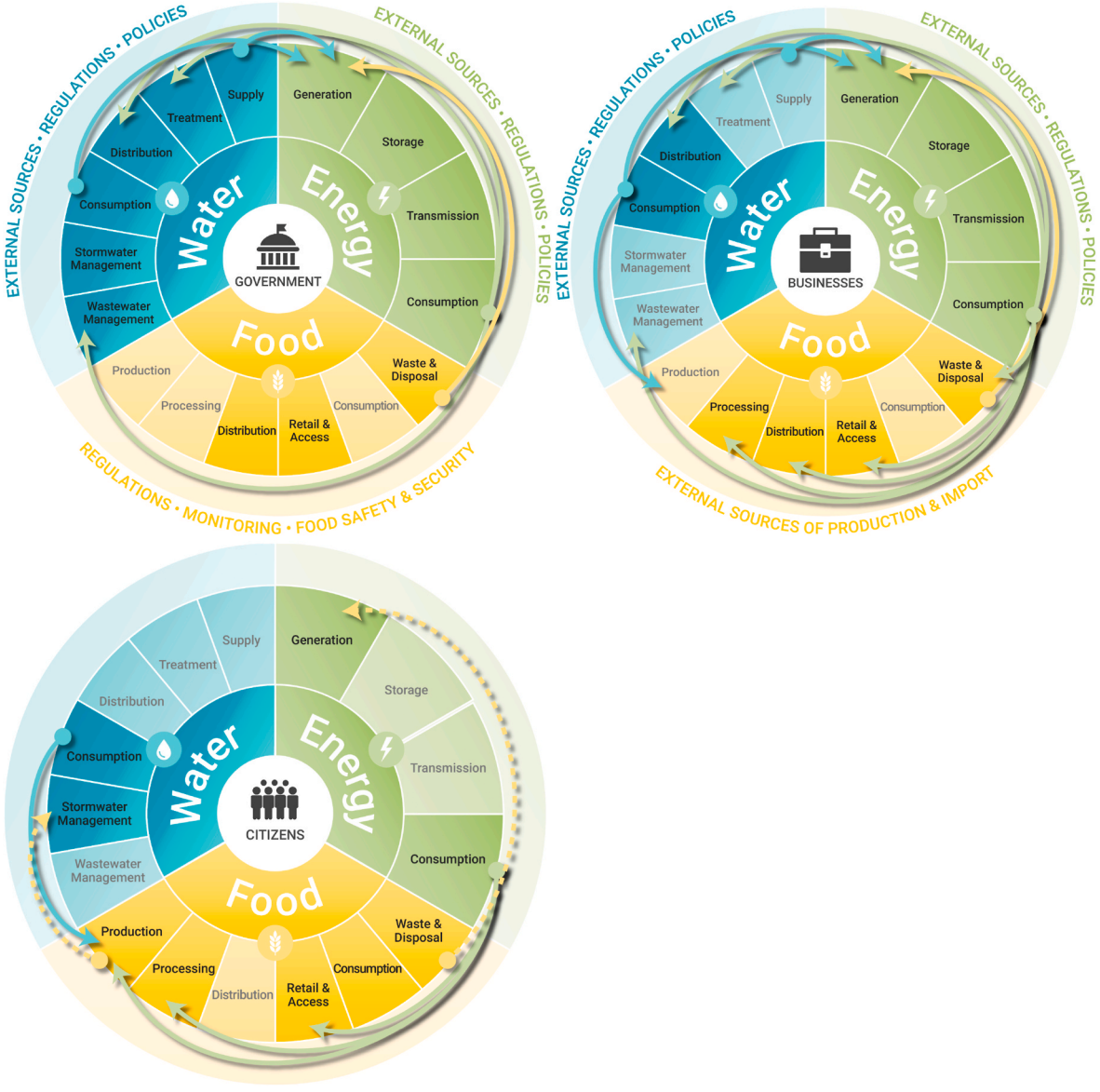

Fig. 3. Interactions between urban actors, i.e., government (a), businesses (b), and citizens (c) with different elements of the food, water and energy systems. Elements in darker colors indicate those where actors have higher degree of engagement or decision-making power. Solid arrows show primary paths of interaction; dashed arrows indicate potential connections. Black text indicates primary activities for this group, grey text indicates activities where this group does not usually contribute.

different spatial and temporal scales for different stakeholders. In some cities water and energy generation and supply may be operated and regulated by local government, or may be fully privatized and responsive to government regulations.

In this approach we recognize that depending on the local context, the actors may have varying degrees of power and influence as well as different ways of engagement with the water, food and energy systems. These levels of engagement may be tangible (i.e., using water to produce food) or intangible (i.e., voting to influence water or energy regulations). We also highlight the role of external (outside the urban boundary or local actor sphere of influence) factors. Urban areas, especially mid-size or small cities need to be considered within a larger geographic area. The discussion about urban FWE nexus is typically placed within a larger environmental (i.e., watershed) or regulatory (i.e., county or state) context. We illustrate some of these external factors in Fig. 3. They may include sources of water, food and energy that exist outside of cities, or policies and regulations that affect access to resources. Identifying these tangible and intangible connections can help reduce the ambiguity of the FWE nexus, and facilitate a multi-stakeholder dialog about integrated governance. Mapping common connections between FWE systems' elements for different stakeholders can make overlapping interests more visible and promote shared knowledge, data or resources. Furthermore, it can highlight the capacity of different stakeholders to authorize and act upon FWE nexus related decisions (Laborgne et al., 2021).

The benefit of this expanded depiction of FWE nexus is that it permits us both to address the obvious FWE nexus linkages used in analytical approaches (e.g. Karabulut et al., 2016) and at varying spatial scales (Bijl et al., 2018; Kliskey et al., 2021), and the more theoretical linkages between different stakeholders (e.g. Daher et al., 2019; Kropf et al., 2021; Purwanto et al., 2019). In particular, by considering each of spheres of engagement or layers (Cottee et al., 2016) separately, the common connections between FWE nexus elements and key actors become more apparent (Dalla Fontana et al., 2021; Kropf et al., 2021). This additional transparency can then form a basis for improving FWE nexus governance by maximizing the common interests between different stakeholders, and being able to engage citizens or community groups in FWE nexus activities. For example, Halbe et al. (2015) used stakeholder interviews and participatory modeling to identify sustainability issues that are prevalent in Cyprus, and to frame these in the context of the FWE nexus. While this example is not strictly focused on the urban scale, it illustrates how the FWE is pertinent to local community interests. High water consumption for food production, and energy consumption for seawater desalination provided an obvious FWE nexus perspective. Stakeholders ranged from concerned citizens and community groups, through to policy-makers and business groups. They found that the participatory model, comparing different stakeholder perceptions and assessing case-specific innovations, identified multiple levels at which changes can commence and the responsibilities of different stakeholders.

Our literature review demonstrated that considerable research has already been undertaken on the FWE nexus, and interest is growing in the urban FWE nexus. However, gaps still exist in urban FWE nexus governance and the incorporation of citizen science to build empirical knowledge and implement the FWE nexus at urban scales. The FWE governance actor mapping along with the urban living labs (ULLs) can help visualize the connections and provide an environment for unpacking a seemingly ambiguous FWE nexus thinking. It can also present an opportunity for inclusion of different urban stakeholders in the conversation about different elements of food, water and energy systems and their effect on the quality of life within the broader goals of urban resilience and sustainability (e.g. Laborgne et al., 2021).

5. Conclusions and future directions

The growing body of literature on the FWE nexus underscores the relevance of this topic as modern society faces rapid urbanization, growing population, and with this an increasing demand on water, food and energy resources. Initially proposed as a mechanism to promote sustainable use of resources, the FWE nexus concept has evolved over the past decade through various disciplinary perspectives and management goals. Many papers reviewed in this article are driven by a common goal to characterize or theorize the FWE nexus as a system and to describe or quantify the connections between food, water and energy sectors or systems. However, despite this common system-thinking approach and a motivation to promote efficient and sustainable resource management, the literature shows that the FWE nexus concept is subject to many interpretations, conceptual models, and methods. Similar to other interdisciplinary concepts such as sustainability and resilience, the FWE nexus concept can be repeatedly framed, conceptualized and contested, depending on the scholarly inquiry or disciplinary perspective (Romero-Lankao et al., 2016).

A large number of the review articles published in recent years indicate the need for a better understanding of the FWE nexus topic. These reviews and our synthesis of the state of knowledge demonstrate that, on one hand, the flexibility of the FWE nexus concept promotes diversity of quantitative and qualitative methods and models, thus advancing the science and context-specific understanding of the FWE nexus. On the other hand, the absence of common definitions and the ambiguity and complexity of existing conceptual and analytical FWE nexus frameworks limit the application of the FWE nexus in practice for an integrated governance and resource management.

A decade of research on the FWE nexus since the 2011 Bonn conference clearly articulates that connections, interactions and interdependencies between the three resource sectors or systems exist. However, these connections vary across spatial scales and levels of governance and may have different meanings and representations depending on local policies and management practices. Despite the large volume of peer-reviewed literature on the FWE nexus, our review demonstrated that only a small fraction of the empirical studies represent local (e.g., urban or community) scale that involves communities or citizens as active participants in the FWE nexus governance. Moreover, there is very little knowledge in the literature to guide studies aiming to connect an integrated multi-level FWE nexus governance with innovative data visualization and participatory processes. Laborgne et al. (2021) find that this lack of translation from research to practice, in addition to within and across disciplines, arises from the abstract nature of the FWE nexus and invisibility of the interlinkages between FWE nexus elements. They advocate an urban living lab (ULL) approach to co-create the interfaces between knowledge, governance, administrative and social systems, to make the nexus connections more tangible.

In this paper, we have reviewed the FWE nexus literature, paying special attention to the urban-scale applications and quantitative and qualitative data that have been used to represent the full spectrum of the FWE nexus as well as data to represent each system and sector. We searched the literature and synthesized examples from the original research papers on FWE nexus governance, and stakeholder engagement process. Finally, we analyzed existing frameworks and their applicability to the local-scale FWE nexus research and implementation. A recurrent theme in the literature is the difficulty of adopting an abstract theoretical concept into a practicable governance framework (e.g. Dalla Fontana et al., 2021; Urbinatti et al., 2020b; van Gevelt, 2020), with transparency being at the heart of the problem (Laborgne et al., 2021). Our synthesis of the state of knowledge, informed the development of the roadmap that aims to reduce the ambiguity associated with the FWE nexus concepts.

Rapid urbanization, population growth, and increasing demand for food, water, and energy contribute to fundamental transformation of the earth system. The complexity of urban socio-ecological systems placed within a broader context of global environmental change, use of resources, and sustainability goals requires better understanding of the FWE systems and the nexus governance at all scales of decision-making.

Disaggregating the nexus into component systems helps to unpack the complexity of water, energy and food systems into sub-elements (e.g., production, distribution, storage, consumption, waste) and identify existing or potential spheres of engagement for different groups of governance actors with the systems. This approach makes the connections more visible and helps to determine what quantitative (e.g., spatial) or quantitative (e.g., stakeholder interviews) data can represent the FWE nexus. By mapping urban actors and their interactions with different elements of the FWE systems, we can also explore the potential for common connections, overlapping interests and shared knowledge, data or resources, thus making progress towards more integrated FWE nexus governance.

Declaration of competing interest

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

Acknowledgements

This study was conducted in the Creating Interfaces project, funded within the framework of the Sustainable Global Urban Initiative (SUGI) Food-Water-Energy Nexus program. This program has been set up by the Belmont Forum and the Joint Programming Initiative (JPI) Urban Europe and has received funding from the European Union's Horizon, 2020 research and innovation program under grant agreement # 730254 and the following national funding agencies: The U.S. National Science Foundation (NSF) funded this work under grant #1830933, the German Federal Ministry of Education and Research (BMBF) funded this work under grant # 01UV1803A, the National Science Center (NCN) of Poland funded this work under grant #UMO-2017/25/Z/HS6/03046, and the Executive Agency for Higher Education, Research, Development and Innovation (UEFISCDI), of Romania funded this work under grant #COFUND-ERANET-ENSUGI-Creating Interfaces. The National Center for Atmospheric Research is sponsored by NSF.

References

Abraham, M.A., 2018. Introduction to the special section on the food, energy, water Nexus. Environ. Prog. Sustain. Energy 37 (1). https://doi.org/10.1002/ep.12861, 20–20.

Abulibdeh, A., Zaidan, E., 2020. Managing the water-energy-food nexus on an integrated geographical scale. Environmental Development 33, 100498. https://doi.org/10.1016/j.envdev.2020.100498.

Al-Ansari, T., Korre, A., Nie, Z., Shah, N., 2015. Development of a life cycle assessment tool for the assessment of food production systems within the energy, water and food Nexus. Sustain. Prod. Consum. 2, 52–66. https://doi.org/10.1016/j.spc.2015.07.005.

Al-Saidi, M., Elagib, N.A., 2017. Towards understanding the integrative approach of the water, energy and food Nexus. Sci. Total Environ. 574, 1131–1139. https://doi.org/10.1016/j.scitotenv.2016.09.046.

Albrecht, T.R., Crootof, A., Scott, C.A., 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.

Allan, T., Keulertz, M., Woertz, E., 2015. The water–food–energy Nexus: an introduction to Nexus concepts and some conceptual and operational problems. Int. J. Water Resour. Dev. 31 (3), 301–311. https://doi.org/10.1080/07900627.2015.1029118.

Artioli, F., Acuto, M., McArthur, J., 2017. The water-energy-food Nexus: an integration agenda and implications for urban governance. Polit. Geogr. 61, 215–223. https://doi.org/10.1016/j.polgeo.2017.08.009.

Azapagic, A., 2015. Special issue: sustainability issues in the food–energy–water Nexus. Sustain. Prod. Consum. 2, 1–2. https://doi.org/10.1016/j.spc.2015.08.002.

Babaie, H., Davarpanah, A., Dhakal, N., 2019. Projecting pathways to food–energy–water systems sustainability through ontology. Environ. Eng. Sci. 36 (7), 808–819. https://doi.org/10.1089/ees.2018.0551.

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R.S.J., Yumkella, K.K., 2011. Considering the energy, water and food nexus: towards an integrated modelling approach. Energy Pol. 39 (12), 7896–7906. https://doi.org/10.1016/j.enpol.2011.09.039.

Beck, M.B., Villarroel Walker, R., 2013. On water security, sustainability, and the water-food-energy-climate Nexus. Front. Environ. Sci. Eng. 7 (5), 626–639. https://doi.org/10.1007/s11783-013-0548-6.

Bielicki, J.M., Beetstra, M.A., Kast, J.B., Wang, Y., Tang, S., 2019. Stakeholder perspectives on sustainability in the food-energy-water nexus. Front. Environ. Sci. 7 https://doi.org/10.3389/fenvs.2019.00007.

Biggs, E.M., Bruce, E., Boruff, B., Duncan, J.M.A., Horsley, J., Pauli, N., et al., 2015. Sustainable development and the water–energy–food Nexus: a perspective on livelihoods. Environ. Sci. Pol. 54, 389–397. https://doi.org/10.1016/j.envsci.2015.08.002.

Bijl, D.L., Bogaart, P.W., Dekker, S.C., van Vuuren, D.P., 2018. Unpacking the Nexus: different spatial scales for water, food and energy. Global Environ. Change 48, 22–31. https://doi.org/10.1016/j.gloenvcha.2017.11.005.

Bizikova, L., 2019. Integrating the water-energy-food Nexus into policy and decision-making. In: Koulouri, A., Mouraviev, N. (Eds.), Policy and Governance in the Water-Energy-Food Nexus. Routledge, pp. 31–47. https://doi.org/10.4324/9780429427718-3.

Bizikova, L., Roy, D., Swanson, D., Venema, H.D., McCandless, M., 2013. The Water–Energy–Food Security Nexus: towards a practical planning and decision-support framework for landscape investment and risk management. Winnipeg, Canada. Retrieved from. https://www.iisd.org/sites/default/files/publications/wef_Nexus_2013.pdf.

Bogardi, J.J., Dudgeon, D., Lawford, R., Flinkerbusch, E., Meyn, A., Pahl-Wostl, C., et al., 2012. Water security for a planet under pressure: interconnected challenges of a changing world call for sustainable solutions. Curr. Opin. Environ. Sustain. 4 (1), 35–43. https://doi.org/10.1016/j.cosust.2011.12.002.

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.

Bullock, J.B., Bowman, A.O., 2018. Exploring citizens' support for policy tools at the food, energy, water Nexus. Environ. Prog. Sustain. Energy 37 (1), 148–154. https://doi.org/10.1002/ep.12727.

Burkhard, B., de Groot, R., Costanza, R., Seppelt, R., Jørgensen, S.E., Potschin, M., 2012a. Solutions for sustaining natural capital and ecosystem services. Ecol. Indicat. 21, 1–6. https://doi.org/10.1016/j.ecolind.2012.03.008.

Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012b. Mapping ecosystem service supply, demand and budgets. Ecol. Indicat. 21, 17–29. https://doi.org/10.1016/j.ecolind.2011.06.019.

Cai, X., Wallington, K., Shafiee-Jood, M., Marston, L., 2018. Understanding and managing the food-energy-water Nexus – opportunities for water resources research. Adv. Water Resour. 111 (April, 2017), 259–273. https://doi.org/10.1016/j.advwatres.2017.11.014.

Caputo, S., Schoen, V., Specht, K., Grard, B., Blythe, C., Cohen, N., Fox-Kämper, R., Hawes, J., Newell, J., Poniży, L., 2021. Applying the food-energy-water nexus approach to urban agriculture: from FEW to FEWP (Food-Energy-Water-People). Urban For. Urban Green. 58, 126934 https://doi.org/10.1016/j.ufug.2020.126934.

Chance, E., Ashton, W., Pereira, J., Mulrow, J., Norberto, J., Derrible, S., Guilbert, S., 2018. The Plant-An experiment in urban food sustainability. Environ. Prog. Sustain. Energy 37 (1), 82–90. https://doi.org/10.1002/ep.12712.

Clarens, A.F., Peters, C.A., 2016. Mitigating climate change at the carbon water nexus: a call to action for the environmental engineering community. Environ. Eng. Sci. 33 (10), 719–724. https://doi.org/10.1089/ees.2016.0455.

Codoban, N., Kennedy, C.A., 2008. Metabolism of neighborhoods. J. Urban Plann. Dev. 134 (1), 21–31. https://doi.org/10.1061/(ASCE)0733-9488(2008)134:1(21).

Cottee, J., López-Avilés, A., Behzadian, K., Bradley, D., Butler, D., Downing, C., et al., 2016. The local nexus network: exploring the future of localised food systems and associated energy and water supply. In: Setchi, R., Howlett, R., Liu, Y., Theobald, P. (Eds.), Sustainable Design and Manufacturing, 2016. SDM, 2016. Smart Innovation, Systems and Technologies, vol. 52. Springer, Chania, Greece, pp. 613–624. https://doi.org/10.1007/978-3-319-32098-4_52.

Covarrubias, M., 2019. The Nexus between water, energy and food in cities: towards conceptualizing socio-material interconnections. Sustain. Sci. 14 (2), 277–287. https://doi.org/10.1007/s11625-018-0591-0.

Crossman, N.D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., et al., 2013. A blueprint for mapping and modelling ecosystem services. Ecosyst. Serv. 4, 4–14. https://doi.org/10.1016/j.ecoser.2013.02.001.

D'Odorico, P., Davis, K.F., Rosa, L., Carr, J.A., Chiarelli, D., Dell'Angelo, J., et al., 2018. The global food-energy-water nexus. Rev. Geophys. 56 (3), 456–531. https://doi.org/10.1029/2017RG000591.

Daccache, A., Ciurana, J.S., Rodriguez Diaz, J.A., Knox, J.W., 2014. Water and energy footprint of irrigated agriculture in the Mediterranean region. Environ. Res. Lett. 9 (12), 124014 https://doi.org/10.1088/1748-9326/9/12/124014.

Daher, B., Hannibal, B., Mohtar, R.H., Portney, K., 2020. Toward understanding the convergence of researcher and stakeholder perspectives related to water-energy-food (WEF) challenges: the case of San Antonio, Texas. Environ. Sci. Pol. 104, 20–35. https://doi.org/10.1016/j.envsci.2019.10.020.

Daher, B., Hannibal, B., Portney, K.E., Mohtar, R.H., 2019. Toward creating an environment of cooperation between water, energy, and food stakeholders in San Antonio. Sci. Total Environ. 651, 2913–2926. https://doi.org/10.1016/j.scitotenv.2018.09.395.

Dai, J., Wu, S., Han, G., Weinberg, J., Xie, X., Wu, X., et al., 2018. Water-energy Nexus: a review of methods and tools for macro-assessment. Appl. Energy 210 (September, 2017), 393–408. https://doi.org/10.1016/j.apenergy.2017.08.243.

Dalla Fontana, M., Wahl, D., Moreira, F. de A., Offermans, A., Ness, B., Malheiros, T.F., Giulio, Di, M, G., 2021. The five Ws of the water-energy-food nexus: a reflexive approach to enable the production of actionable knowledge. Frontiers in Water 3, 729722. https://doi.org/10.3389/frwa.2021.729722.

Del Borghi, A., Moreschi, L., Gallo, M., 2020. Circular economy approach to reduce water–energy–food nexus. Current Opinion in Environmental Science & Health 13, 23–28. https://doi.org/10.1016/j.coesh.2019.10.002.
de Strasser, L., Lipponen, A., Howells, M., Stec, S., Bréthaut, C., 2016. A methodology to assess the water energy food ecosystems nexus in transboundary river basins. Water 8 (2), 59. https://doi.org/10.3390/w8020059.
Endo, A., Burnett, K., Orencio, P., Kumazawa, T., Wada, C., Ishii, A., et al., 2015. Methods of the water-energy-food nexus. Water 7 (10), 5806–5830. https://doi.org/10.3390/w7105806.
Endo, A., Tsurita, I., Burnett, K., Orencio, P.M., 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. Current Opinion in Environmental Science & Health 13, 46–60. https://doi.org/10.1016/j.coesh.2019.10.004.
Fan, J.-L., Kong, L.-S., Wang, H., Zhang, X., 2019. A water-energy Nexus review from the perspective of urban metabolism. Ecol. Model. 392, 128–136. https://doi.org/10.1016/j.ecolmodel.2018.11.019.
FAO, 2018. Forests and Sustainable Cities: Inspiring Stories from Around the World, ISBN 978-92-5-130417-4.
Feng, C., Qu, S., Jin, Y., Tang, X., Liang, S., Chiu, A.S.F., Xu, M., 2019. Uncovering urban food-energy-water Nexus based on physical input-output analysis: the case of the Detroit Metropolitan Area. Appl. Energy 252, 113422. https://doi.org/10.1016/j.apenergy.2019.113422.
Fernandes Torres, C.J., Peixoto de Lima, C.H., Suzart de Almeida Goodwin, B., Rebello de Aguiar Junior, T., Sousa Fontes, A., Veras Ribeiro, D., Dantas Pinto Medeiros, Y., 2019. A literature review to propose a systematic procedure to develop "nexus thinking" considering the water–energy–food nexus. Sustainability 11 (24), 7205. https://doi.org/10.3390/su11247205.
Frantzeskaki, N., Kabisch, N., 2016. Designing a knowledge co-production operating space for urban environmental governance—lessons from Rotterdam, Netherlands and Berlin, Germany. Environ. Sci. Pol. 62, 90–98. https://doi.org/10.1016/j.envsci.2016.01.010.
Gondhalekar, D., Ramsauer, T., 2017. Nexus city: operationalizing the urban water-energy-food nexus for climate change adaptation in Munich, Germany. Urban Clim. 19, 28–40. https://doi.org/10.1016/j.uclim.2016.11.004.
Grady, C.A., Blumsack, S., Mejia, A., Peters, C.A., 2019. The food–energy–water nexus: security, sustainability, and systems perspectives. Environ. Eng. Sci. 36 (7), 761–762. https://doi.org/10.1089/ees.2019.0170.
Graham, S., 2000. Constructing premium network spaces: reflections on infrastructure networks and contemporary urban development. Int. J. Urban Reg. Res. 24 (1), 183–200. https://doi.org/10.1111/1468-2427.00242.
Greer, R., von Wirth, T., Loorbach, D., 2020. The diffusion of circular services: Transforming the Dutch catering sector. J. Clean. Prod. 267, 121906 https://doi.org/10.1016/j.jclepro.2020.121906.
Guillaume, J., Kummu, M., Eisner, S., Varis, O., 2015. Transferable principles for managing the nexus: lessons from historical global water modelling of central Asia. Water 7 (12), 4200–4231. https://doi.org/10.3390/w7084200.
Gunda, T., Tidwell, V.C., 2019. A uniform practice for conceptualizing and communicating food-energy-water nexus studies. Earth's future, 2019EF001150. https://doi.org/10.1029/2019EF001150.
Hagemann, N., Kirschke, S., 2017. Key issues of interdisciplinary NEXUS governance analyses: lessons learned from research on integrated water resources management. Resources 6 (1), 9. https://doi.org/10.3390/resources6010009.
Halbe, J., Pahl-Wostl, C., Lange, A., M, Velonis, C., 2015. Governance of transitions towards sustainable development – the water–energy–food Nexus in Cyprus. Water Int. 40 (5–6), 877–894. https://doi.org/10.1080/02508060.2015.1070328.
Hannibal, B., Portney, K., 2019. Correlates of food–energy–water nexus awareness among the American public. Soc. Sci. Q. 100 (3), 762–778. https://doi.org/10.1111/ssqu.12590.
Harwood, S.A., 2018. In search of a (WEF) Nexus approach. Environ. Sci. Pol. 83 (January), 79–85. https://doi.org/10.1016/j.envsci.2018.01.020.
Hellegers, P., Zilberman, D., Steduto, P., McCornick, P., 2008. Interactions between water, energy, food and environment: evolving perspectives and policy issues. Water Pol. 10 (S1), 1–10. https://doi.org/10.2166/wp.2008.048.
Holling, C.S., 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Systemat. 4, 1–23.
Hoolohan, C., Larkin, A., McLachlan, C., Falconer, R., Soutar, I., Suckling, J., Varga, L., Haltas, I., Druckman, A., Lumbroso, D., Scott, M., Gilmour, D., Ledbetter, R., McGrane, S., Mitchell, C., Yu, D., 2018. Engaging stakeholders in research to address water–energy–food (WEF) nexus challenges. Sustain. Sci. 13 (5), 1415–1426. https://doi.org/10.1007/s11625-018-0552-7.
Howarth, C., Monasterolo, I., 2016. Understanding barriers to decision making in the UK energy-food-water Nexus: the added value of interdisciplinary approaches. Environ. Sci. Pol. 61, 53–60. https://doi.org/10.1016/j.envsci.2016.03.014.
Huckleberry, J.K., Potts, M.D., 2019. Constraints to implementing the food-energy-water nexus concept: governance in the lower Colorado river basin. Environ. Sci. Pol. 92, 289–298. https://doi.org/10.1016/j.envsci.2018.11.027.
Huntington, H.P., Schmidt, J.I., Loring, P.A., Whitney, E., Aggarwal, S., Byrd, A.G., Dev, S., Dotson, A.D., Huang, D., Johnson, B., Karenzi, J., Penn, H.J.F., Salmon, A., Sambor, D.J., Schnabel, W.E., Wies, R.W., Wilber, M., 2021. Applying the food–energy–water nexus concept at the local scale. Nat. Sustain. 4 (8), 672–679. https://doi.org/10.1038/s41893-021-00719-1.
Hussien, W.A., Memon, F.A., Savic, D.A., 2018. A risk-based assessment of the household water-energy-food Nexus under the impact of seasonal variability. J. Clean. Prod. 171, 1275–1289. https://doi.org/10.1016/j.jclepro.2017.10.094.
Itayi, C.L., Mohan, G., Saito, O., 2021. Understanding the conceptual frameworks and methods of the food–energy–water nexus at the household level for development-oriented policy support: a systematic review. Environ. Res. Lett. 16 (3) https://doi.org/10.1088/1748-9326/abd660, 033006.
Johnson, O.W., Karlberg, L., 2017. Co-exploring the water-energy-food nexus: facilitating dialogue through participatory scenario building. Front. Environ. Sci. 5, 24. https://doi.org/10.3389/fenvs.2017.00024.
Jones, J.L., White, D.D., 2021. A social network analysis of collaborative governance for the food-energy-water nexus in Phoenix, AZ, USA. Journal of Environmental Studies and Sciences. https://doi.org/10.1007/s13412-021-00676-3.
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. Pol. 77, 114–121. https://doi.org/10.1016/j.envsci.2017.07.007.
Kapucu, N., Beaudet, S., Chang, N.-B., Qiu, J., Peng, Z.-R., 2021. Partnerships and network governance for urban food-energy-water (FEW) nexus. Int. J. Publ. Adm. 1–14. https://doi.org/10.1080/01900692.2021.1967981.
Karabulut, A., Egoh, B.N., Lanzanova, D., Grizzetti, B., Bidoglio, G., Pagliero, L., et al., 2016. Mapping water provisioning services to support the ecosystem–water–food–energy Nexus in the Danube river basin. Ecosyst. Serv. 17, 278–292. https://doi.org/10.1016/j.ecoser.2015.08.002.
Kharanagh, S.G., Banihabib, M.E., Javadi, S., 2020. An MCDM-based social network analysis of water governance to determine actors' power in water-food-energy nexus. J. Hydrol. 581, 124382 https://doi.org/10.1016/j.jhydrol.2019.124382.
Keskinen, M., Someth, P., Salmivaara, A., Kummu, M., 2015. Water-energy-food nexus in a transboundary river basin: the case of Tonle Sap lake, Mekong river basin. Water 7 (10), 5416–5436. https://doi.org/10.3390/w7105416.
Keskinen, M., Varis, O., 2016. Water-energy-food nexus in large asian river basins. Water 8 (10). https://doi.org/10.3390/w8100446, 446.
Kliskey, A., Williams, P., Griffith, D.L., Dale, V.H., Schelly, C., Marshall, A.-M., Gagnon, V.S., Eaton, W.M., Floress, K., 2021. Thinking big and thinking small: a conceptual framework for best practices in community and stakeholder engagement in food, energy, and water systems. Sustainability 13 (4), 2160. https://doi.org/10.3390/su13042160.
Kremer, P., DeLiberty, T.L., 2011. Local food practices and growing potential: mapping the case of Philadelphia. Appl. Geogr. 31 (4), 1252–1261. https://doi.org/10.1016/j.apgeog.2011.01.007.
Kropf, B., Schmid, E., Mitter, H., 2021. Multi-step cognitive mapping of perceived nexus relationships in the Seewinkel region in Austria. Environ. Sci. Pol. 124, 604–615. https://doi.org/10.1016/j.envsci.2021.08.004.
Kurian, M., Ardakanian, R., 2015. Governing the Nexus: water, soil and waste resources considering global change. Governing the Nexus: Water, Soil and Waste Resources Considering Global Change. https://doi.org/10.1007/978-3-319-05747-7.
Laborgne, P., Ekille, E., Wendel, J., Pierce, A., Heyder, M., Suchomska, J., Nichersu, I., Balaican, D., Ślebioda, K., Wróblewski, M., Goszczynski, W., 2021. Urban Living Labs: how to enable inclusive transdisciplinary research? Urban Transformations 3 (1), 11. https://doi.org/10.1186/s42854-021-00026-0.
Laspidou, C., Mellios, N., Kofinas, D., 2019. Towards ranking the water–energy–food–land use–climate nexus interlinkages for building a nexus conceptual model with a Heuristic Algorithm. Water 11 (2), 306. https://doi.org/10.3390/w11020306.
Lawford, R.G., 2019. A design for a data and information service to address the knowledge needs of the water-energy-food (W-E-F) nexus and strategies to facilitate its implementation. Front. Environ. Sci. 7. https://doi.org/10.3389/fenvs.2019.00056.
Liang, S., Qu, S., Zhao, Q., Zhang, X., Daigger, G.T., Newell, J.P., et al., 2019. Quantifying the urban food–energy–water nexus: the case of the detroit metropolitan area. Environ. Sci. Technol. 53 (2), 779–788. https://doi.org/10.1021/acs.est.8b06240.
Liu, J., Mao, G., Hoekstra, A.Y., Wang, H., Wang, J., Zheng, C., et al., 2018. Managing the energy-water-food Nexus for sustainable development. Appl. Energy 210, 377–381. https://doi.org/10.1016/j.apenergy.2017.10.064.
Mannan, M., Al-Ansari, T., Mackey, H.R., Al-Ghamdi, S.G., 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.
Melloni, G., Turetta, A., Bonatti, M., Sieber, S., 2020. A stakeholder analysis for a water-energy-food nexus evaluation in an Atlantic forest area: implications for an integrated assessment and a participatory approach. Water 12 (7). https://doi.org/10.3390/w12071977, 1977.
Mirabella, N., Allacker, K., Sala, S., 2019. Current trends and limitations of life cycle assessment applied to the urban scale: critical analysis and review of selected literature. Int. J. Life Cycle Assess. 24 (7), 1174–1193. https://doi.org/10.1007/s11367-018-1467-3.
Mohtar, R.H., Daher, B., 2016. Water-Energy-Food Nexus Framework for facilitating multi-stakeholder dialogue. Water Int. 41 (5), 655–661. https://doi.org/10.1080/02508060.2016.1149759.
Mohtar, R.H., Daher, B., 2019. Lessons learned: creating an interdisciplinary team and using a Nexus approach to address a resource hotspot. Sci. Total Environ. 650, 105–110. https://doi.org/10.1016/j.scitotenv.2018.08.406.
Monstadt, J., Coutard, O., 2019. Cities in an era of interfacing infrastructures: politics and spatialities of the urban Nexus. Urban Stud. 56 (11), 2191–2206. https://doi.org/10.1177/0042098019833907.

Mpandeli, S., Naidoo, D., Mabhaudhi, T., Nhemachena, C., Nhamo, L., Liphadzi, S., et al., 2018. Climate change adaptation through the water-energy-food nexus in Southern Africa. Int. J. Environ. Res. Publ. Health 15 (10), 2306. https://doi.org/10.3390/ijerph15102306.

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.

Newell, J.P., 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) https://doi.org/10.1088/1748-9326/ab0767, 073003.

Nichersu, I., Nichersu, I., Balaican, D., CiobĂnescu, A., Bratfanof, E., 2020. Key indicators and variables in citizen science for the water-food-energy Nexus analysis in Tulcea case study. Key Indicators and Variables in Citizen Science for the Water-Food-Energy Nexus Analysis in Tulcea Case Study 25, 93–100. https://doi.org/10.7427/DDI.25.10.

Ostrom, E., Cox, M., Schlager, E., 2014. An assessment of the institutional analysis and development framework and introduction of the social-ecological systems framework. In: Theories of the Policy Process.

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

Pahl-Wostl, C., Bhaduri, A., Bruns, A., 2018. Editorial special issue: the Nexus of water, energy and food – an environmental governance perspective. Environ. Sci. Pol. 90, 161–163. https://doi.org/10.1016/j.envsci.2018.06.021.

Parsa, A., Van De Wiel, M.J., Schmutz, U., 2021. Intersection, interrelation or interdependence? The relationship between circular economy and nexus approach. J. Clean. Prod. 313, 127794 https://doi.org/10.1016/j.jclepro.2021.127794.

Pierce, A.L., Heyder, M., Tregonning, G., Laborgne, P., Wilhelmi, O., Wendel, J., 2021. In: Brouwer, F. (Ed.), Urban Nexus. Handbook on the Water-Energy-Food Nexus. Edward Elgar Publishers (in press).

Portney, K.E., Hannibal, B., Goldsmith, C., McGee, P., Liu, X., Vedlitz, A., 2018. Awareness of the food–energy–water nexus and public policy support in the United States: public Attitudes among the American people. Environ. Behav. 50 (4), 375–400. https://doi.org/10.1177/0013916517706531.

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

Ramaswami, A., Boyer, D., Nagpure, A.S., Fang, A., Bogra, S., Bakshi, B., et al., 2017. An urban systems framework to assess the trans-boundary food-energy-water Nexus: implementation in Delhi, India. Environ. Res. Lett. 12 (2) https://doi.org/10.1088/1748-9326/aa5556, 025008.

Rasul, G., Sharma, B., 2016. The Nexus approach to water–energy–food security: an option for adaptation to climate change. Clim. Pol. 16 (6), 682–702. https://doi.org/10.1080/14693062.2015.1029865.

Roidt, M., Avellán, T., 2019. Learning from integrated management approaches to implement the Nexus. J. Environ. Manag. 237, 609–616. https://doi.org/10.1016/j.jenvman.2019.02.106.

Romero-Lankao, P., Bruns, A., Wiegleb, V., 2018. From risk to WEF security in the city: the influence of interdependent infrastructural systems. Environ. Sci. Pol. 90, 213–222. https://doi.org/10.1016/j.envsci.2018.01.004.

Romero-Lankao, P., Gnatz, D., Wilhelmi, O., Hayden, M., 2016. Urban sustainability and resilience: from theory to practice. Sustainability 8 (12). https://doi.org/10.3390/su8121224, 1224.

Romero-Lankao, P., McPhearson, T., Davidson, D.J., 2017. The food-energy-water Nexus and urban complexity. Nat. Clim. Change 7 (4), 233–235. https://doi.org/10.1038/nclimate3260.

Romero-Lankao, P., Norton, R., 2018. Interdependencies and risk to people and critical food, energy, and water systems:, 2013 Flood, Boulder, Colorado, USA. Earth's future 6 (11), 1616–1629. https://doi.org/10.1029/2018EF000984.

Sahely, H.R., Dudding, S., Kennedy, C.A., 2003. Estimating the urban metabolism of Canadian cities: greater Toronto Area case study. Can. J. Civ. Eng. 30 (2), 468–483. https://doi.org/10.1139/l02-105.

Schmidt, J.J., Matthews, N., 2018. From state to system: financialization and the water-energy-food-climate Nexus. Geoforum 91, 151–159. https://doi.org/10.1016/j.geoforum.2018.03.001.

Schulterbrandt Gragg, R., Anandhi, A., Jiru, M., Usher, K.M., 2018. A conceptualization of the urban food-energy-water nexus sustainability paradigm: modeling from theory to practice. Front. Environ. Sci. 6 https://doi.org/10.3389/fenvs.2018.00133.

Shannak, S., Mabrey, D., Vittorio, M., 2018. Moving from theory to practice in the water-energy-food nexus: an evaluation of existing models and frameworks. Water-Energy Nexus. https://doi.org/10.1016/j.wen.2018.04.001.

Sharmina, M., Hoolohan, C., Bows-Larkin, A., Burgess, P.J., Colwill, J., Gilbert, P., Howard, D., Knox, J., Anderson, K., 2016. A nexus perspective on competing land demands: Wider lessons from a UK policy case study. Environ. Sci. Pol. 59, 74–84. https://doi.org/10.1016/j.envsci.2016.02.008.

Smajgl, A., Ward, J., Pluschke, L., 2016. The water–food–energy Nexus – realising a new paradigm. J. Hydrol. 533, 533–540. https://doi.org/10.1016/j.jhydrol.2015.12.033.

Song, G., Han, Y., Li, J., Lv, D., 2019. The potential water-food-health Nexus in urban China: a comparative study on dietary changes at home and away from home. Sci. Total Environ. 657, 1173–1182. https://doi.org/10.1016/j.scitotenv.2018.12.157.

Soomro, K., Bhutta, M.N.M., Khan, Z., Tahir, M.A., 2019. Smart city big data analytics: an advanced review. Wiley Interdisciplinary Reviews: Data Min. Knowl. Discov., e1319 https://doi.org/10.1002/widm.1319.

Sperling, J.B., Berke, P.R., 2017. Urban nexus science for future cities: focus on the energy-water-food-X nexus. Current Sustainable/Renewable Energy Reports 4 (3), 173–179. https://doi.org/10.1007/s40518-017-0085-1.

Spiegelberg, M., Baltazar, D.E., Sarigumba, M.P.E., Orencio, P.M., Hoshino, S., Hashimoto, S., et al., 2017. Unfolding livelihood aspects of the water–energy–food nexus in the dampalit watershed, Philippines. J. Hydrol.: Reg. Stud. 11, 53–68. https://doi.org/10.1016/j.ejrh.2015.10.009.

Stein, C., Pahl-Wostl, C., Barron, J., 2018. Towards a relational understanding of the water-energy-food Nexus: an analysis of embeddedness and governance in the Upper Blue Nile region of Ethiopia. Environ. Sci. Pol. https://doi.org/10.1016/j.envsci.2018.01.018.

Stoker, G., 1998. Governance as theory: five propositions. Int. Soc. Sci. J. 50 (155), 17–28. https://doi.org/10.1111/1468-2451.00106.

Taherzadeh, O., Bithell, M., Richards, K., 2018. When defining boundaries for Nexus analysis, let the data speak. Resour. Conserv. Recycl. 137, 314–315. https://doi.org/10.1016/j.resconrec.2018.06.012.

Talozi, S., Al Sakaji, Y., Altz-Stamm, A., 2015. Towards a water–energy–food Nexus policy: realizing the blue and green virtual water of agriculture in Jordan. Int. J. Water Resour. Dev. 31 (3), 461–482. https://doi.org/10.1080/07900627.2015.1040544.

Taniguchi, M., Endo, A., Gurdak, J.J., Swarzenski, P., 2017. Water-energy-food nexus in the Asia-pacific region. J. Hydrol.: Reg. Stud. 11, 1–8. https://doi.org/10.1016/j.ejrh.2017.06.004.

Teisl, M.F., Bell, K.P., Noblet, C.L., 2017. Special issue on the economics of changing Coastal resources: the nexus of food, energy, and water systems. Agric. Resour. Econ. Rev. 46 (2), 175–185. https://doi.org/10.1017/age.2017.25.

UN (United Nations), 2012. World urbanization prospects: the 2011 revision. United Nations Department of Economic and Social Affairs Population Division. http://esa.un.org/unup/pdf/WUP2011_Highlights.pdf.

Urbinatti, A.M., Benites-Lazaro, L.L., Carvalho, C.M., de, Giatti, L.L., 2020a. 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.

Urbinatti, A.M., Dalla Fontana, M., Stirling, A., Giatti, L.L., 2020b. 'Opening up' the governance of water-energy-food nexus: towards a science-policy-society interface based on hybridity and humility. Sci. Total Environ. 744, 140945 https://doi.org/10.1016/j.scitotenv.2020.140945.

van Gevelt, T., 2020. The water–energy–food nexus: Bridging the science–policy divide. Current Opinion in Environmental Science & Health 13, 6–10. https://doi.org/10.1016/j.coesh.2019.09.008.

Veldhuis, A.J., Glover, J., Bradley, D., Behzadian, K., López-Avilés, A., Cottee, J., Yang, A., 2019. Re-distributed manufacturing and the food-water-energy Nexus: opportunities and challenges. Prod. Plann. Control 30 (7), 593–609. https://doi.org/10.1080/09537287.2018.1540055.

Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., Kimmich, C., 2015. The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks. Water Altern. (WaA) 8 (1), 735–755.

Vinca, A., Riahi, K., Rowe, A., Djilali, N., 2021. Climate-land-energy-water nexus models across scales: progress, gaps and best Accessibility practices. Front. Environ. Sci. 9, 691523 https://doi.org/10.3389/fenvs.2021.691523.

Wahl, D., Ness, B., Wamsler, C., 2021. Implementing the urban food–water–energy nexus through urban laboratories: a systematic literature review. Sustain. Sci. 16 (2), 663–676. https://doi.org/10.1007/s11625-020-00893-9.

Weitz, N., Strambo, C., Kemp-Benedict, E., Nilsson, M., 2017. Closing the governance gaps in the water-energy-food Nexus: insights from integrative governance. Global Environ. Change 45, 165–173. https://doi.org/10.1016/j.gloenvcha.2017.06.006.

White, D., Jones, J., Maciejewski, R., Aggarwal, R., Mascaro, G., 2017. Stakeholder analysis for the food-energy-water nexus in Phoenix, Arizona: implications for nexus governance. Sustainability 9 (12), 2204. https://doi.org/10.3390/su9122204.

Wichelns, D., 2017. The water-energy-food Nexus: is the increasing attention warranted, from either a research or policy perspective? Environ. Sci. Pol. 69, 113–123. https://doi.org/10.1016/j.envsci.2016.12.018.

Willemen, L., Hein, L., Verburg, P.H., 2010. Evaluating the impact of regional development policies on future landscape services. Ecol. Econ. 69 (11), 2244–2254. https://doi.org/10.1016/j.ecolecon.2010.06.012.

Williams, J., Bouzarovski, S., Swyngedouw, E., 2019. The urban resource nexus: on the politics of relationality, water–energy infrastructure and the fallacy of integration. Environment and Planning C. Politics and Space 37 (4), 652–669. https://doi.org/10.1177/0263774X18803370.

Wolde, Z., Wei, W., Kunpeng, W., Ketema, H., 2020. Local community perceptions toward livelihood and water–energy–food nexus: a perspective on food security. Food and Energy Security 9 (3). https://doi.org/10.1002/fes3.207.

World Economic Forum WEF, 2011. Water Security: the Water-Food-Energy-Climate Nexus. World Economic Forum. Island Press/Center for Resource Economics, Washington, DC. https://doi.org/10.5822/978-1-61091-026-2.

Yan, W., Roggema, R., 2019. Developing a design-led approach for the food-energy-water nexus in cities. Urban Planning 4 (1), 123. https://doi.org/10.17645/up.v4i1.1739.

Yung, L., Louder, E., Gallagher, L.A., Jones, K., Wyborn, C., 2019. How methods for navigating uncertainty connect science and policy at the water-energy-food nexus. Front. Environ. Sci. 7 https://doi.org/10.3389/fenvs.2019.00037.

Zhang, P., Zhang, L., Chang, Y., Xu, M., Hao, Y., Liang, S., et al., 2019. 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.

Zimmerman, R., Zhu, Q., Dimitri, C., 2018. A network framework for dynamic models of urban food, energy and water systems (FEWS). Environ. Prog. Sustain. Energy 37 (1), 122–131. https://doi.org/10.1002/ep.12699.

Ziv, G., Watson, E., Young, D., Howard, D.C., Larcom, S.T., Tanentzap, A.J., 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.